# NAVAL POSTGRADUATE SCHOOL

**MONTEREY, CALIFORNIA**

# THESIS

**MODELING THE EFFECTS OF A TRANSPORTATION SECURITY INCIDENT UPON THE MARINE TRANSPORTATION SYSTEM**

by

Edward D. Pidgeon

June 2008

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**MODELING THE EFFECTS OF A TRANSPORTATION SECURITY INCIDENT UPON THE MARINE TRANSPORTATION SYSTEM**

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Submitted in partial fulfillment of the
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# ABSTRACT

We introduce a simulation model to evaluate the disruptions, delays, and incremental costs inflicted on the U.S. West Coast container shipping industry by a Transportation Security Incident (TSI). Each year, more than 6,000 container ships call upon West Coast seaports handling in excess of 18.3 million containers. Current national directives do not specify uniform standards for measuring the amount of seaport cargo-handling capacity, nor decision rules to divert cargo to alternate facilities when a primary destination is degraded or unusable. Through analysis, we identify infrastructure components that are potential bottlenecks and/or vulnerable to a TSI that can potentially threaten the U.S. maritime shipping capacity. For example, we demonstrate a 10-day labor union dispute and longshoremen work stoppage that paralyzes the entire U.S. West Coast. The incident induces significant port congestion from Puget Sound to San Pedro Bay, reducing the annual West Coast vessel and import container throughput by 3 percent (174 vessels and 237,088 containers), and increases the incremental costs suffered by ocean carriers by $400 million. Additional analysis identifies opportunities for commercial and government investment in additional seaport infrastructure to alleviate West Coast port congestion, while ensuring the unimpeded continuity of operations of West Coast shipping subsequent to a TSI.

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# TABLE OF CONTENTS

## LIST OF FIGURES

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# LIST OF TABLES

# LIST OF SYMBOLS, ACRONYMS, AND ABBREVIATIONS

| | |
|---|---|
| AAPA | American Association of Port Authorities |
| APL | American President Lines |
| APM | A.P. Moller-Maersk |
| BOC | Bureau of the Census, an agency of the Department of Commerce |
| BNSF | Burlington Northern Santa Fe, a Western United States rail carrier |
| BTS | Bureau of Transportation Statistics |
| CFR | Code of Federal Regulations |
| COSCO | China Ocean Shipping Company |
| CPSM | Container Port Simulation Model |
| DHS | Department of Homeland Security |
| DOT | Department of Transportation |
| DWT | Deadweight ton, a measure of ship displacement |
| FEU | Forty-foot Equivalent Unit |
| GAO | Government Accounting Office |
| GDP | Gross Domestic Product |
| ILWU | International Longshoremen and Warehousemen's Union |
| ISO | International Organization for Standardization |
| LNG | Liquefied Natural Gas |
| MARAD | Maritime Administration, an agency of the Department of Transportation |
| MSRAM | Maritime Security Risk Assessment Model |
| MTS | Marine Transportation System |
| MTSA | Maritime Transportation Security Act |
| NOA | Notice of Arrival |
| NSMS | National Strategy for Maritime Security |
| NVMC | National Vessel Movement Center |
| PMA | Pacific Maritime Association |
| POLA | Port of Los Angeles |
| POLB | Port of Long Beach |
| POO | Port of Oakland |
| POP | Port of Portland |

| | |
|---|---|
| POS | Port of Seattle |
| POSD | Port of San Diego |
| POT | Port of Tacoma |
| TEU | Twenty-foot Equivalent Units, a measure of container volume |
| TOTE | Totem Ocean Trailer Express |
| TSA | Transportation Security Administration |
| TSI | Transportation Security Incident |
| TWIC | Transportation Worker Identification Credential |
| UP | Union Pacific, a Western United States rail carrier |
| USCG | United States Coast Guard |

# EXECUTIVE SUMMARY

The United States economy, national security and the American way of life are critically dependent upon the efficient, effective and unimpeded movement of cargoes via our nation's seaports and the Marine Transportation System (MTS). Each year, approximately 6,000 ocean carriers make 90,000 port calls to U.S. seaports and carry 95 percent of the international trade transiting North America. Similarly, 90 percent of American manufactured and export goods move intermodally to our nation's seaports and contribute in excess of $800 billion annually to the Gross Domestic Product (GDP). Of particular importance to our economic security is the vitality of the West Coast container shipping industry. Seven major West Coast seaports (Seattle, Tacoma, Portland, Oakland, Los Angeles, Long Beach and San Diego) account for approximately 40 percent and in excess of $443 billion of total U.S. waterborne trade annually. In addition, these seaports handle more than 50 percent of the entire U.S. waterborne foreign container trade, more than the combined efforts of East and Gulf Coast seaports. Because of this demonstrated economic importance of our West Coast seaports, it is imperative that their operations remain uninterrupted.

A Transportation Security Incident (TSI) is any natural or human-caused event that results in a significant loss of life, environmental damage, transportation system or economic disruption in a particular area. A TSI such as a terrorist attack or natural disaster incapacitating one or more of our seaports can inflict a severe ripple effect on other modes of transportation, as well as have adverse economic or national security effects.

Current national maritime directives do not specify uniform standards for measuring domestic seaport cargo-handling capacity nor decision rules to divert cargo to alternate facilities when a primary destination is rendered unusable or degraded subsequent to a TSI. In the aftermath of such an event, the operational decisions to divert cargo to alternate sites will be based upon real-time information obtained by the shippers about the current status of seaports and intermodal systems. Because a majority of shipping industry assets are privately owned and operated, government officials are

restricted from directing the private shipping industry how to operate their vessels subsequent to a TSI. However, we assume shippers will respond to minimize their costs and schedule disruptions.

We present a multistage simulation called the Container Port Simulation Model (CPSM) to evaluate the disruptions, delays and additional costs inflicted on the U.S. West Coast container shipping industry by a TSI. We implement CPSM with the Arena simulation software and devise a set of six hypothetical TSI scenarios. Our objectives, first to identify and quantify the disruption and incremental costs following a TSI, and then to identify which infrastructure components are potential bottlenecks and/or vulnerable to a TSI that threatens our maritime shipping capacities.

We implement CPSM and successfully identify seaport and intermodal areas that are potential bottlenecks and vulnerable to a TSI. Our results reveal the insufficiency of existing West Coast infrastructure to accommodate a simultaneous interruption of operations at the ports of Los Angeles and Long Beach for 14 days, ports that account for nearly 70 percent of the total West Coast volume. Such an event also exacerbates coastal congestion enough to degrade the annual West Coast volume by 2% (61 ships and 162,242 containers) and cost shippers in excess of $439 million beyond normal expenses. Another scenario identifies a 10-day labor union dispute as the single most disruptive threat to West Coast shipping that degrades annual coastal throughput by 3% (174 ships and 237,088) and assesses shippers $400 million in incremental costs. CPSM does not take into account the economic impact on local, national and global economies. Lastly, we are able to identify the value of additional investment in West Coast seaport infrastructure (by commercial and government entities) that could alleviate West Coast congestion and ensure the continuity of operations of the West Coast shipping industry subsequent to a TSI.

CPSM provides commercial and government maritime agencies a baseline model to identify and quantify the disruption, congestion and incremental costs incurred to ocean carriers in the aftermath of maritime incident. In addition, CPSM provides a new database of our nation's West Coast container port volumes and capacities. By altering model parameters, such as vessel characteristics and interarrival and service times, as

well as seaport and intermodal infrastructures and capacities, CPSM can assist planners to identify carrier, port or other coastal vulnerabilities and determine where tradeoffs and investments can be made to mitigate TSI vulnerabilities.

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# I. INTRODUCTION

## A. PURPOSE OF THE STUDY

This thesis introduces a simulation model to identify and measure the effects of congestion at container ports on the West Coast of the United States and shipper costs subsequent to a Transportation Security Incident (TSI) upon the these ports and the Marine Transportation System (MTS). The Maritime Transportation Security Act (MTSA) of 2002, a program designed to ensure greater security for United States seaports, defines a TSI as “a security incident that results in a significant loss of life, environmental damage, transportation system disruption, or economic disruption in a particular area” (MTSA, 2002). Whether a TSI follows a natural disaster such as an earthquake or tidal wave, or is a much more worrisome event caused by an intelligent adversary, we are concerned with how best to continue operating our surviving critical infrastructure.

Current national infrastructure directives do not specify uniform standards for measuring domestic seaport cargo-handling capacity, nor decision rules to divert cargo to alternate facilities when a primary source or destination facility is rendered unusable or degraded. Additionally, major freight corridors to and from U.S. seaports are key supporting infrastructures that influence our maritime cargo-handling capacity, congestion, and delays, yet there are little organized data describing these channels. The ultimate purpose of this thesis is two-fold: First, identify and quantify the disruption and incremental costs following a TSI at container ports on the West Coast of the United States, and then identify which of these ports contain infrastructure components that are potential bottlenecks and/or vulnerable to a TSI that threatens maritime shipping capacities, thus indicating they would benefit from incremental investments or government subsidies.

## B. IMPORTANCE OF THE STUDY

A terrorist attack, or similarly disruptive incident of national significance involving the MTS system, can cause a severe ripple effect on other modes of

transportation, as well as have adverse economic or national security effects. The MTS consists of those waterways, ports, and intermodal landside connections that allow various modes of transportation to move people and goods to, from, and on the water. Physically, the MTS is composed of the following:

- 361 seaports (see Figure 1);
- 95,000 miles of coastline; the Great Lakes and the St. Lawrence Seaway;
- 3,700 marine terminals;
- 25,000 miles of navigable channels;
- 238 locks at 192 locations;
- 3.4 million square miles of Exclusive Economic Zones;
- 174,000 miles of rail connecting all 48 contiguous states, as well as Canada and Mexico; over 45,000 miles of interstate highway, supported by over 115,000 miles of other roadways;
- over 1,400 intermodal connections and thousands of bridges, dams, and levees; and,
- dockworkers, cargo handlers, logisticians, port infrastructure, and the complex web of national, regional, and international relationships that support the supply-chain economies throughout the world (USCG, 2008).

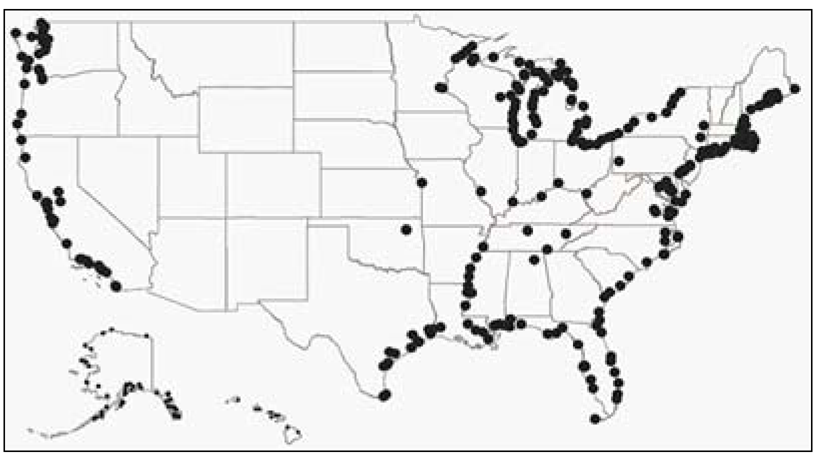

Figure 1. The locations of U.S. seaport facilities vital to the Marine Transportation System (From: GAO, 2005).

The U.S. economy, national defense, and the American standard of living are dependent upon the unimpeded viability of the MTS. Economically, a majority of the nation's commercial maritime activities are concentrated in about a dozen major seaports

that annually account for over 90 percent of U.S. imports, valued in excess of $800 billion, which arrive via containerized cargo vessels (BTS, 2007).

> The Marine Transportation System is an integral part of our nation's economy and even a temporary incapacitation at the local level can have a dramatic impact throughout the region and nation (DOT, 1999).

The MTS is a vital artery to the 440 military installations of the United States, enabling ready avenues of supply and mobilization for our armed forces in the event of routine and large-scale military deployments. Additionally, the MTS provides the American populace with greater access to domestic and world markets via an affordable and reliable means of transportation.

We develop a means to assess domestic port cargo-handling capacity, identifying infrastructure vulnerabilities susceptible to a naturally-occurring or human-caused event of significance, and assist in expediting recovery of the MTS in the wake of a TSI. This work provides an analytical tool for commercial and government entities to assess TSI impacts to a particular seaport or region (in terms of cost impacts of time delays). In peacetime, we cannot influence private shipping companies' redirection of assets; however, we can advertise the best alternatives in terms of their incremental costs. Ocean carriers are well-advised to follow our lead, because we will anticipate these changes, and perhaps influence operation of, or even enhancement of, infrastructure to support these ocean carriers. As it stands, the private shipping industry maintains its own enterprise continuity plans based upon proprietary information. Operational decisions to divert cargo to alternate sites, including foreign ports, will be based upon real-time operational information about the transportation and intermodal systems.

> In the aftermath of a Transportation Security Incident, the recovery of critical infrastructures, resumption of the Marine Transportation System, and restoration of communities within the affected area must all occur simultaneously and expeditiously (NSMS, 2005).

We seek to learn how private sector and government agencies can cooperate to ensure continuity of operations; in particular, the resumption or redirection of maritime commercial activities, including the movement of cargoes to mitigate the larger economic, social, and possible national security effects of the incident.

## C. WHAT WE ARE DOING TO SOLVE THE PROBLEM

We demonstrate a simulation model of the U.S. West Coast marine container-handling infrastructure by tracing every container ship from its passage of a U.S. Coast Guard-mandated, 96-hour Notice of Arrival (NOA) threshold, to its intended destination and subsequent container transfers thereafter. Utilizing five years of actual traffic and container history, and observing operations under normal conditions, we model and stress eight West Coast ports with abnormal events ranging from a significant reduction in seaport personnel and intermodal operators to wholesale denial of access to an entire port, or worse. Because the U.S. Government cannot tell ocean carriers how to operate their vessels following a TSI, we assume they will (or should) respond to minimize their costs and schedule disruptions. Our goal is to induce such ocean-carrier behavior and gauge the global costs of each TSI event.

# II. THE OPERATIONAL ENVIRONMENT

## A. MARINE TRANSPORTATION SYSTEM (MTS)

The MTS is complex and both geographically and physically diverse in character and operation. It is a critical component of America's military and economic security, in addition to a source of recreational value to the American populace.

Economically, the MTS is part of the foundation of America's economic growth and prosperity. The U.S. is the world's largest and most active trading partner, as over 95 percent of North American trade (equivalent to 2 billion tons of domestic and international freight) enters the country through U.S. seaports annually. Additionally, the MTS supports in excess of 13 million jobs and contributes more than $800 billion annually to the U.S. gross domestic product (GDP) (NSMS, 2005).

The MTS faces significant challenges in the near future. First, it needs to accommodate growing levels of consumer demand as international maritime trade is expected to more than double by the year 2020, particularly international container traffic. Nowhere will this pressure be felt more than at seaports. As trade volumes increase, the capacity of America's total intermodal transportation system must increase in order to maintain and expand the nation's economy (MARAD, 2005). Additionally, the security of the MTS will continue to be challenged by both human and naturally-occurring threats that might disrupt the continuity of operations. Our nation's seaports, in particular, are inherently vulnerable to a TSI as they are sprawling, reliant on supporting complex transportation networks, are easily accessible by water and land, and are normally adjacent to crowded metropolitan areas (Martin Associates, 2007).

The continued health of our economy, our military prowess, and our way of life is dependent upon the MTS. The goal of both industry and government is to protect the MTS against a catastrophic event, while ensuring the unimpeded continuity of maritime operations subsequent to such an event.

## B. WEST COAST CONTAINER SHIPPING INDUSTRY

The West Coast shipping industry is vital to the health and prosperity of local, domestic, and global economies. It serves as a gateway of international waterborne trade between the U.S., the Middle East, Asia, and Pacific Rim countries. The exports and imports through West Coast ports are important elements in America's manufacturing and agricultural bases, and contribute significantly to the American quality of life.

The West Coast seaport states of Washington, Oregon, and California have experienced significant growth in tonnage over the past 30 years, from a reported 60 million tons in 1970, to 361 million in 2006. During this period, the composition of cargo throughput has changed dramatically with the advent of containerization (Martin Associates, 2007). Containerization is a system of intermodal cargo transport using standard International Organization for Standardization (ISO) containers that can be loaded onto and transported by container ships, trucks, railroad cars, and planes. This research, and modern-day container cargo and shipping, revolves around the twenty-foot equivalent container, or TEU. Table 1 highlights the dimensions and variants of the TEU most commonly used today. Similarly, we consider the Panamax ocean carrier for our research. Panamax container ships are the largest that can navigate through the locks of the Panama Canal. Post-Panamax or "Over-Panamax" ships are larger (see Table 2).

| Modern Container Sizes and TEU Capacities | | | | |
|---|---|---|---|---|
| **Length** | **Width** | **Height** | **Volume** | **TEU** |
| 20 feet (6.1 m) | 8 feet (2.4 m) | 8.5 feet (2.6 m) | 1,360 cubic feet | 1 |
| 40 feet (12 m) | 8 feet (2.4 m) | 8.5 feet (2.6 m) | 2,720 cubic feet | 2 |
| 45 feet (14 m) | 8 feet (2.4 m) | 8.5 feet (2.6 m) | 3,060 cubic feet | 2 or 2.25 |
| 53 feet (16 m) | 8 feet (2.4 m) | 8.5 feet (2.6 m) | 3,604 cubic feet | 2.65 |

Table 1. Dimensions and variants of the twenty-foot equivalent (TEU), a focus of our research. Two TEUs are equivalent to one (1) forty-foot equivalent, or FEU (From: JANES, 1994).

| Container Ship Class | Panamax Class | Post-Panamax Class |
|---|---|---|
| **Length** | 1,000 ft (305 m) | 1,400 ft (427 m) |
| **Width** | 106 ft (32.30 m) | 180 ft (55.00 m) |
| **Draft** | 39.5 ft (12.00 m) | 60 ft (18.23 m) |
| **TEUs** | 5,000 | 12,000 |
| **Deadweight Tonnes (DWT)** | 65,000 > | 65,000 < |

Table 2. Dimensional comparison of the Panamax and Post-Panamax container vessels. Panamax vessels, a focus of our study, exhibit the largest dimensions capable of transiting the Panama Canal (From: Lloyd's Register, 2008).

Per the Pacific Maritime Association (PMA), representative of West Coast ocean carriers, terminal operators, and stevedoring companies, West Coast ports reported handling 8.7 million tons of containerized tonnage in 1970, or only 15 percent of the total West Coast tonnage. By 2006, West Coast containerized cargo grew to 259.9 million tons, 72 percent of the total West Coast tonnage (PMA, 2006) and represented $443 billion and 39.5 percent of the total U.S. waterborne trade (BOC, 2006).

Since 1999, West Coast container handling efforts (imports, exports, and empties) efforts have gradually surpassed the combined efforts of both U.S. Gulf and East Coast ports. During this period, the West Coast has annually accounted for more than 50 percent of the United States' total waterborne foreign container trade (see Figure 2). There are two reasons for this: First, a booming surge in international trade from Middle Eastern and Pacific Rim countries, coupled with increasing U.S. demand, make it more advantageous (in terms of cost and distance) for ocean carriers to use trans-Pacific routes to move containerized goods to North America, vice the longer Suez Canal-Mediterranean Sea-Atlantic Ocean transit. Second, today's larger container vessels (i.e., post-Panamax and greater) are unable to transit the Panama Canal to Gulf and East Coast seaports, nor have the majority of East Coast ports maintained the infrastructure to accommodate the increasing dimensions of modern container carriers.

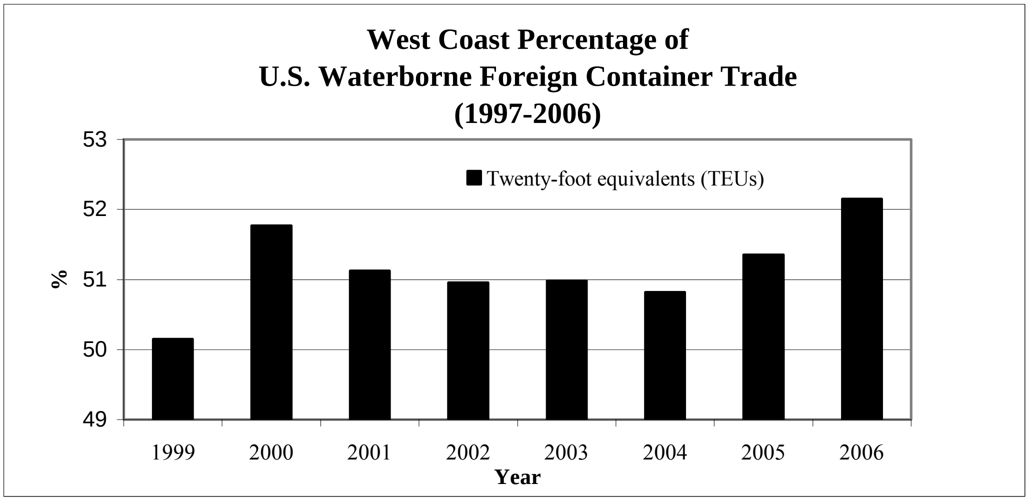


Figure 2. Illustrates the gradual increase in waterborne foreign container trade through West Coast seaports from 1999-2006. In 2006, West Coast seaports accounted for more than 52 percent of import containers into the United States, while Gulf and East Coast ports accounted for the rest (From: BTS, 2007).

Similarly, container carriers have begun to gradually overtake other means of ocean transport. For example, in 2006, in excess of 6,000 ocean carriers made 89,115 vessel calls to U.S. seaports. Twenty-two percent of the total vessel calls were accomplished by container vessels (see Figure 3). Also in 2006, of the 24,086 vessel calls made to West Coast seaports, the largest fraction of these calls (29 percent) were made by container vessels (see Figure 4).

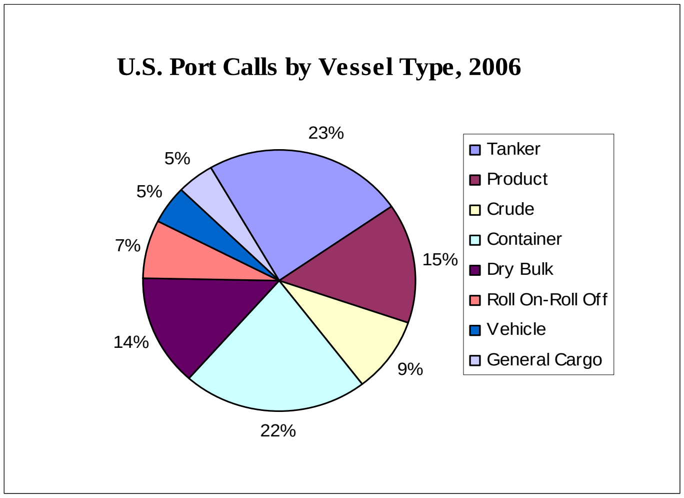


Figure 3. Percentage of vessel types calling upon U.S. ports in 2006. Twenty-two percent of the 89,115 vessel calls were made by container ships, second only to fuel and Liquefied Natural Gas (LNG) tankers (From: MARAD, 2008a).

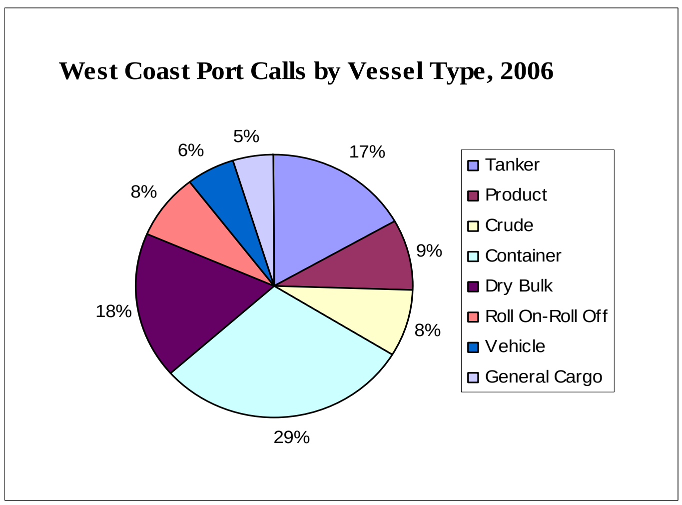


Figure 4. Percentage of vessel types calling upon West Coast ports (Washington, Oregon, and California) in 2006. The largest fraction is the twenty-nine percent of all vessel calls made by container ships (From: MARAD, 2008a).

As worldwide economies continue to develop, the importance of the West Coast shipping industry as an economic catalyst will continue to increase. Growing international and trans-Pacific trade not only account for millions of jobs and stimulate the economies of the West Coast region, but these ports and the cargo they handle support the industrial, retail, and agricultural sectors throughout the United States. Providing these key linkages between the American consumer and industrial and

agricultural sectors are the West Coast ports located in California, Oregon, and Washington, which we now discuss.

## C. WEST COAST SEAPORTS

Our research models the vessel and cargo throughput of eight West Coast seaports, including Seattle, Tacoma, Portland, Oakland, Los Angeles, Long Beach, San Diego, and Punta Colonet (Mexico), a proposed Mexican seaport expected to be operational by 2012 (see Figure 5).


Figure 5. The locations of seaports for our research are (North to South) 1. Seattle, 2. Tacoma, 3. Portland, 4. Oakland, 5. Los Angeles, 6. Long Beach, 7. San Diego and 8. Punta Colonet (Mexico) (After: Google Earth, 2008).

We focus on these seaports due to the magnitude of their contribution to the U.S. container shipping industry. For example, in 2006, 18.3 million import containers entered the United States as part of international trade. Of this number, 59 percent, or 10.8 million TEUs, entered through the West Coast seaports included in our research (BTS, 2007) (see Figure 6). More significantly, of the total handled containers (empty, full, domestic, and international) along the West Coast in 2006, 70 percent were handled

at the Southern California seaports of Los Angeles and Long Beach, while Pacific Northwest seaport traffic was 19 percent and Oakland's 11 percent accounted for the remainder (PMA, 2006).

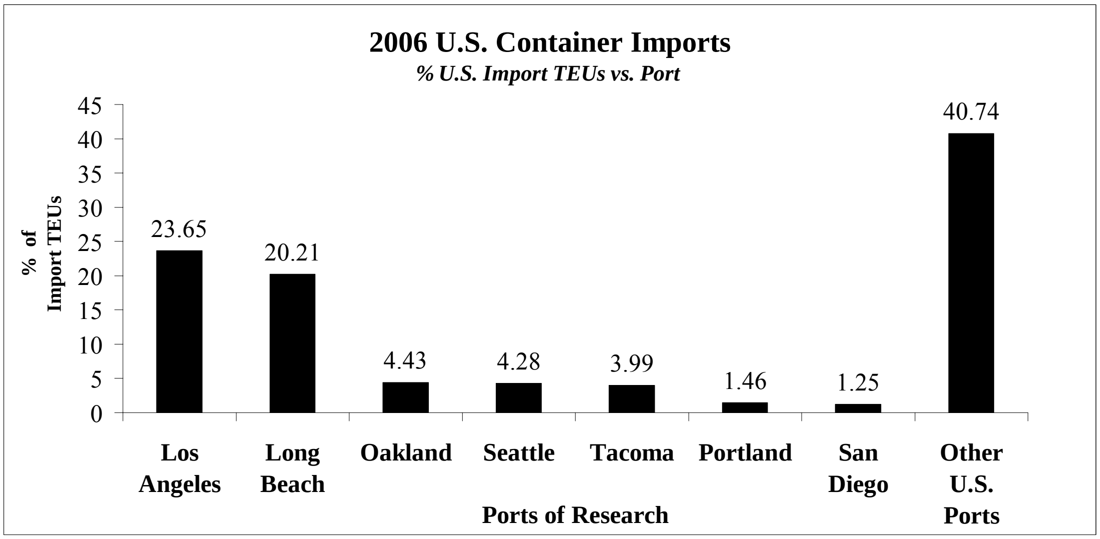


Figure 6. The percentages of U.S. import containers transiting the seven U.S. West Coast ports of this research. Combined, these seven West Coast seaports accounted for 59 percent of import containers during 2006 (After: BTS, 2007).

### 1. Seattle, Washington

The Port of Seattle (POS) is vital to the health of the West Coast shipping industry, as it serves as a mainstay of container shipping in the Pacific Northwest and Puget Sound region. In 2006, the Port of Seattle accounted for 8.8 percent of the total tonnage throughout all West Coast seaports, 80.3 percent of which was containerized. This equates to 1.3 million containers, or TEUs, handled (imports and exports) or 8.5 percent of the 2006 total West Coast container throughput (PMA, 2006).

On average, 769 container vessels call upon Seattle in a given year, bearing in excess of 600,000 import TEUs (MARAD, 2008a). Major containerized imports include machinery, grain and seed, fish and seafood, and paper products from Asia, South America, and Pacific Rim countries with which Seattle has strong trading ties.

Seattle operates eight marine terminals within three harbors (North, Central, and South Harbors) on Puget Sound and Elliot Harbor (see Figure 7). The South Harbor

maintains four container terminals (Terminals 5, 18, 25, and 46) and operates 11 berths, 25 cranes, and 500 acres of container yard. The port is host to major ocean carriers including American President Lines (APL), Maersk-Sealand, Hapag-Lloyd, and Yang Ming Lines. Intermodal operations are supported by access to nearby interstate highways (I-5 and I-90) and on-dock rail facilities serviced by Burlington Northern Santa Fe (BNSF) and Union Pacific (UP) rail carriers (see Figure 8).

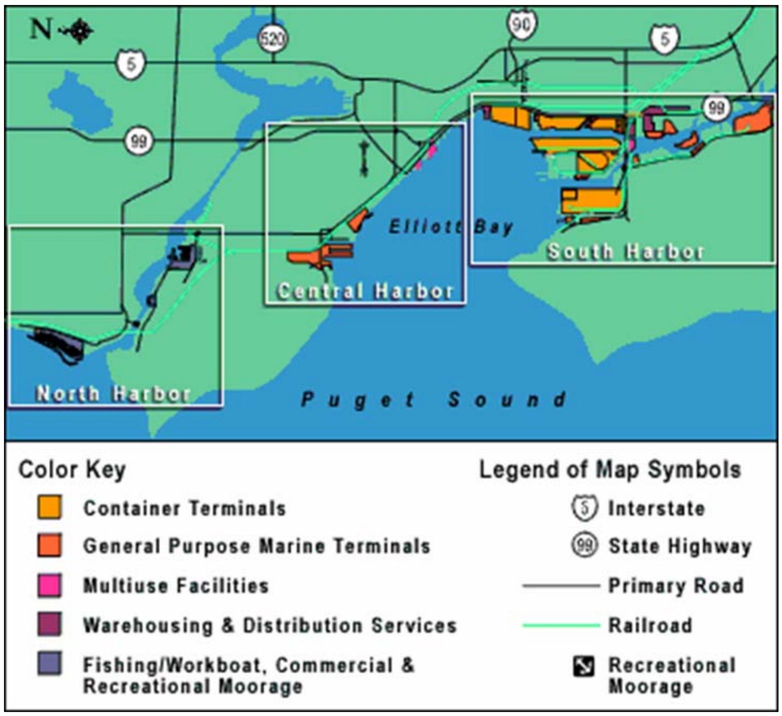


Figure 7. The location of marine terminals at the Port of Seattle. The four container terminals (Terminals 5, 18, 25, and 46) are located in the South Harbor (From: POS, 2008).

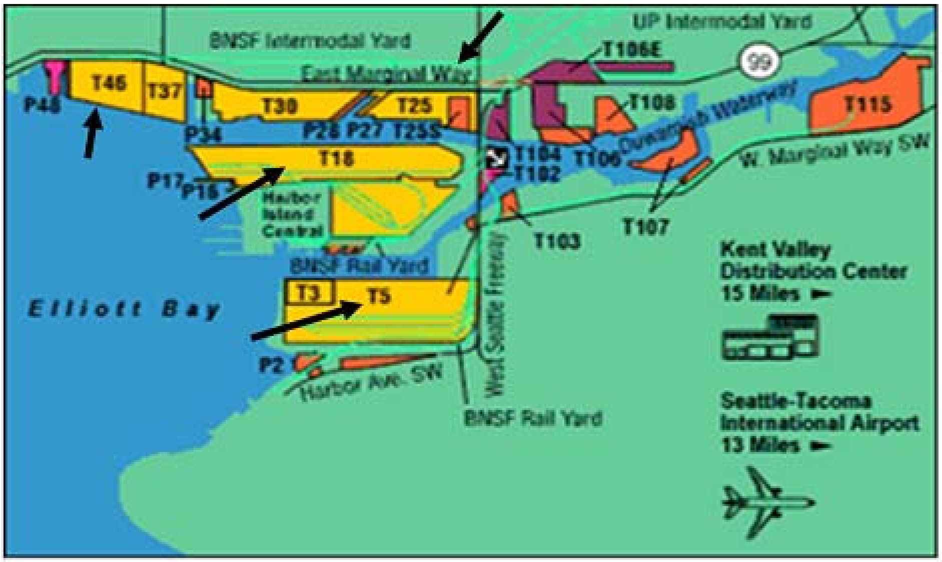


Figure 8. The Port of Seattle South Harbor container terminals (Terminals 5, 18, 25, and 46) are marked by arrows. Intermodal operations are supported by BNSF and UP intermodal yards and access to major highways (After: POS, 2008).

### 2. Tacoma, Washington

The Port of Tacoma (POT), located on Commencement Bay in southern Puget Sound, is a gateway for international trade with Asian countries and serves as a major economic hub for the Pacific Northwest region. More than 70 percent of Tacoma's international container cargo comes from, or is going to, the central and eastern regions of North America. Additionally, Tacoma's domestic commerce includes the handling of more than 70 percent of the marine cargo moving between the lower 48 states and Alaska (POT, 2008).

In 2006, the port accounted for 10.2 percent of the total tonnage throughout West Coast seaports, 69.2 percent of which was containerized. This equates to 1.35 million TEUs handled (imports and exports) or 8.9 percent of the total West Coast container throughput (PMA, 2006).

Tacoma is a major hub for bulk, break-bulk, container, automobile, and heavy-lift cargoes. On average, 570 container vessels call at Tacoma in a given year, bearing in excess of 643,000 import TEUs laden with major imports such as machinery, clothing, textiles, and rubber products.

Tacoma maintains six container terminals (Totem Ocean Trailer Express [TOTE], Husky, Washington United, Pierce County, Olympic Container, and A.P. Moller-Maersk [APM]) (see Figure 9) and operates nine container ship berths, 22 cranes, and 613 acres of container yard. The port is host to major ocean carriers that include Maersk-Sealand, Evergreen, and Kawasaki Kisen Kaisha, or "K" Line. Intermodal operations are supported by four dockside intermodal rail yards serviced by BNSF and UP rail carriers and access to nearby major interstate highways (I-5 and I-90) and state roads.


Figure 9. Locations of container terminals at the Port of Tacoma include 1. TOTE, 2. Husky, 3. Washington United, 4. Pierce County, 5. Olympic Container, and 6. APM (After: Google Earth, 2008).

### 3. Portland, Oregon

The Port of Portland (POP) is a premier Pacific Northwest deep-draft port that maintains strong trading ties with China and other Asian partners. In 2006, Portland was responsible for 5.6 percent of total tonnage throughout all West Coast seaports, 14.0 percent of which was containerized cargo. This equates to 166,563 TEUs handled (imports and exports) or 1.1 percent of West Coast container throughput (PMA, 2006).

On average, 139 container vessels call upon Portland in a given year, bearing in excess of 65,000 import TEUs laden with major imports including electronics, clothing, tires, and furniture.

Portland operates four marine terminals (Terminals 2, 4, 5, and 6) with Terminal 6 dedicated solely to containers (see Figure 10). Terminal 6 operates three deepwater berths, eight cranes, and 200 acres of container yard (see Figure 11). The port is host to major ocean carriers that include China Overseas Shipping Company (COSCO), Hapag-Lloyd, Hanjin Shipping, "K" Line, and Yang Ming Lines. Intermodally, access to major north-south and east-west interstates (I-5 and I-84), and near-dock rail facilities supported by BNSF and UP rail carriers, ensure containerized cargo moves quickly and reliably to inland destinations.


Figure 10. This figure shows the location of Portland's container Terminal 6 in relation to Terminals 2, 4, and 5 that handle bulk and break-bulk commodities. Major rail and highway arteries support Portland's intermodal operations (From: POP, 2008).


Figure 11. Overhead view of Portland's Terminal 6 container facility. The picture shows 1. vessel berthing and gantry cranes, 2. the Columbia River, 3. container yards, and 4. rail facilities (After: Google Earth, 2008).

### 4. Oakland, California

As the fourth busiest container port in North America (AAPA, 2008), the Port of Oakland (POO) is a major international trading hub for bulk, break-bulk, container, automobile, and heavy-lift cargoes from Asia, Europe, Australia, and other South Pacific Islands. Oakland loads and discharges more than 99 percent of the containerized goods moving through Northern California, the nation's fourth-largest metropolitan area (POO, 2008). In 2006, Oakland accounted for 9.4 percent of total tonnage throughout the West Coast seaports, 81.4 percent of which was containerized cargo. This equates to 1.6 million TEUs handled (imports and exports) or 10.6 percent of West Coast container throughput (PMA, 2006). On average, 1,926 container vessels call upon Oakland in a given year, bearing in excess of 638,000 TEUs laden with major imports including beverages, machinery, mineral fuels and oils, construction material, and automobiles.

The port occupies 19 miles of waterfront on the eastern shore of San Francisco Bay, devoting an extensive 900 acres to maritime activities. Oakland operates 12 container terminals, 25 deepwater berths, and 35 container cranes. The port is host to 30 major ocean carriers that include APL, COSCO, Evergreen, "K" Line, and

Maersk-Sealand. Oakland operates two intermodal container yards supported by BNSF and UP rail carriers and has access to major interstates (I-880 and I-980) and state roads (see Figure 12).

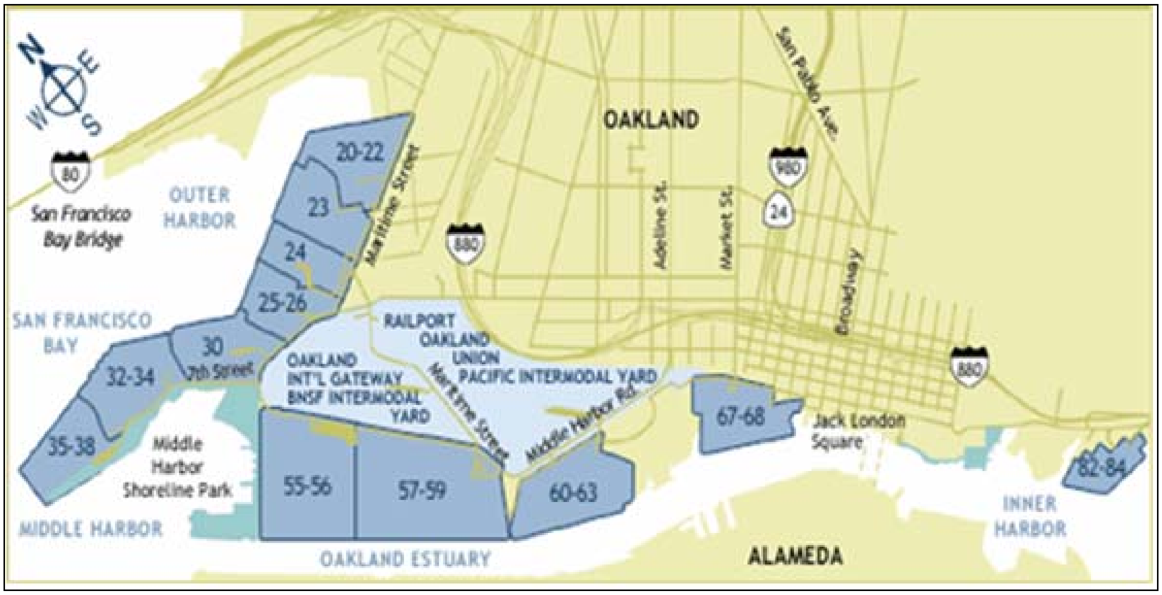


Figure 12. The Port of Oakland's container terminals are shaded dark gray and border the Oakland Estuary and the San Francisco Bay. The port is supported by access to major interstates (I-880) and state roads (From: POO, 2008).

### 5. Los Angeles, California

The Port of Los Angeles (POLA) is the largest and busiest container port in North America (AAPA, 2008) and is a critical gateway of international commerce to the continent. Major trading partners include China, Japan, Taiwan, Thailand, and South Korea, and international trade from these countries accounted for $184 billion in trade revenue in 2007 (POLA, 2008). In 2006, Los Angeles accounted for 31.3 percent of the total import tonnage along the West Coast and 4.5 million import TEUs (PMA, 2006).

On average, 1,108 container vessels call upon Los Angeles annually, laden with furniture, apparel, toys and sporting goods, vehicle and vehicle parts, and electronic products. The 7,500-acre port, located adjacent to the Port of Long Beach (POLB) and situated on San Pedro Bay, encompasses 43 miles of waterfront and 27 total cargo terminals. The port operates eight major container terminals (West Basin [2], TransPacific, Port of Los Angeles, Yusen, Seaside, APL, and APM; see Figure 13), 30

container vessel berths, 68 cranes, and 1,686 acres of container yard. The port is host to 80 different major ocean carriers and is intermodally supported by major interstate (I-110 and I-710) access, four dockside intermodal rail yards, and a near-dock container transfer facility located five miles from the port. The port is a major economic force throughout Southern California, the West Coast, and the United States, as the port is responsible for 1.1 million jobs in the Los Angeles vicinity alone and 3.3 million throughout the country.


Figure 13. Overhead view of the Port of Los Angeles container terminals that include 1. West Basin (Berth 100), 2. West Basin (Berths 121-131), 3. TransPacific, 4.Port of Los Angeles, 5. Yusen, 6. Seaside, 7. APL, and 8. APM (After: Google Earth, 2008).

### 6. Long Beach, California

The Port of Long Beach is the second-largest container port in the United States (AAPA, 2008) and is a channel for international trade from Asia and the Middle East to

North America. East Asian trade accounts for about 90 percent of the shipments through the Port, as top trading partners into Long Beach include China, South Korea, Hong Kong, and Japan.

In 2006, Long Beach accounted for 26.9 percent of the total West Coast tonnage and 30.8 percent or 3.63 million import TEUs (PMA, 2006). On average, 1,846 container vessels call annually to Long Beach carrying major imports including petroleum, electronics, plastics, furniture, and clothing.

The 3,200-acre port operates seven container piers (California United, Hanjin, International, Long Beach, Pacific, and two by Stevedoring Services of America [SSA]; see Figure 14), 50 container berths, 71 cranes, and 1,284 acres of container yard. The port is host to more than 50 major ocean carriers and is supported intermodally by access to major highways and state roads in the Los Angeles-Long Beach area, and on-dock and near-dock rail facilities. Long Beach, like the neighboring Port of Los Angeles (POLA), is a major economic force in Southern California; it supports more than 30,000 Long Beach jobs, 316,000 jobs throughout Southern California, and 1.4 million jobs throughout the United States (POLB, 2008).


Figure 14. Overhead view of the Port of Long Beach container piers that includes 1. California United, 2.Hanjin, 3. International, 4. Long Beach, 5. Pacific, 6a. SSA, and 6b. SSA (After: Google Earth, 2008).

#### 7. San Diego, California

The Port of San Diego (POSD) serves as a transshipment facility for trans-Pacific trade to the southwestern United States and Mexico. In 2006, San Diego accounted for 1.9 percent of the total tonnage throughout the West Coast, 12.4 percent of which was containerized. This equates to 487,000 TEUs handled (imports and exports) or 0.3 percent of the total West Coast container throughput (PMA, 2006). On average, 50 container vessels call upon San Diego in a given year, bearing in excess of 45,000 TEUs laden with major imports such as refrigerated goods, fertilizers, and forest products.

The port operates three marine terminals with one terminal, the Tenth Avenue Marine Terminal, dedicated solely to container shipping (see Figure 15). The container terminal operates eight berths, three cranes, and maintains 25 acres of container yard (see Figure 16). The port maintains a robust on-dock rail facility and is in close proximity to a major interstate (I-5) and state roads throughout the southwestern United States and Mexico.


Figure 15. Port of San Diego Terminal locations include 1. Cruise Ship Terminal, 2. Tenth Avenue Marine Container and 3. National City Marine Terminal (After: POSD, 2008).

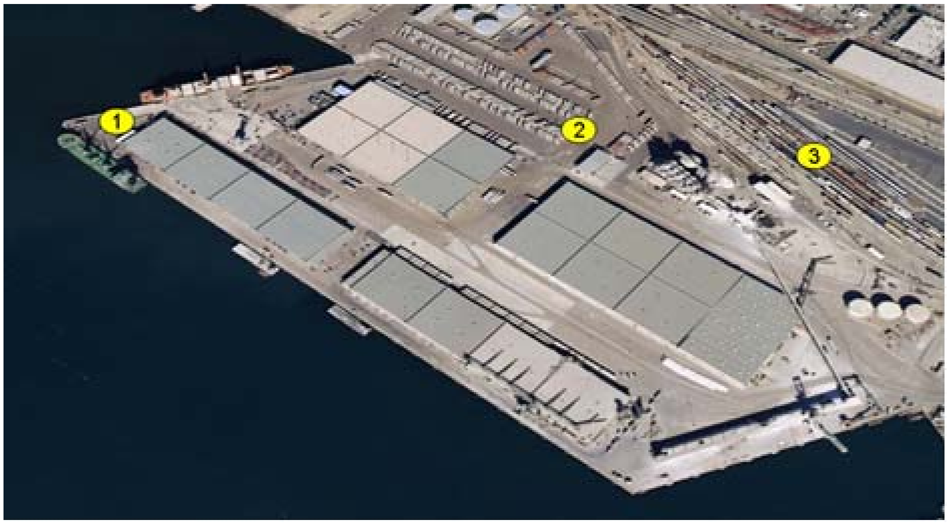


Figure 16. The Port of San Diego Tenth Marine Container Terminal includes 1. vessel berthing and crane support, 2. container yards, and 3. rail facilities (After: Google Earth, 2008).

#### 8. Punta Colonet, Mexico

Mexican authorities are currently soliciting a proposal for the construction of a Baja California seaport capable of challenging the West Coast shipping stronghold of Southern California seaports. If built at the proposed location of Punta Colonet, Mexico 150 miles south of Tijuana, Mexico (see Figure 17), it would serve as a viable option for ocean carriers to bypass the congestion of Southern California ports. Expected to be operational by 2012, Punta Colonet is anticipated to be initially capable of handling one-seventh the current volume of the Port of Los Angeles. Upon full operational capability, the $4 billion port is destined to become one of the largest shipping container facilities on the West Coast, capable of handling in excess of 1 million containers per year with highway and rail access to the southwestern United States. For our research, Punta Colonet serves a "super port" equipped with sufficient berthing and intermodal capabilities to accommodate any diverted vessels subsequent to a TSI at West Coast seaports.


Figure 17. The location of the proposed seaport at Punta Colonet, Mexico, 150 miles south of Tijuana. If constructed, the port will challenge the West Coast shipping stronghold of Southern California ports (From: Baja Insider, 2008).

This is not the first Mexican port to challenge the Southern California shipping monopoly. The Mexican West Coast seaport of Lazaro Cárdenas, a deepwater port that handles container, dry bulk, and liquid cargo, currently handles in excess of 180,000 TEUs per year, with expansion currently underway to handle 2.2 million containers per year by 2012. Through an innovative series of international agreements, infrastructure improvements and new technologies, Lazaro Cárdenas has developed efficient trade corridors to Kansas City, Chicago, and Houston, enabling Asian-based carriers alternate routing to U.S. markets by bypassing Southern California ports (Falche, 2007).

# III. MODEL DEVELOPMENT

## A. RESEARCH SOFTWARE

### 1. Arena

The Arena simulation modeling system is a flexible and powerful tool that allows analysts to create animated simulation models that accurately represent virtually any system (Takus and Profozich, 1997). Arena software is designed to analyze impact changes involving significant and complex redesigns associated with supply chain, manufacturing, processes, logistics, distribution and warehousing, and service systems (Kelton, Sadowski, & Sturrock, 2007). Arena is applicable to our research because the software is designed to identify process bottlenecks, queue build-ups, and the utilization of resources as well as analyze and predict system performance metrics to include costs, throughput, cycle-time, and utilization of material-handling components. Arena has been credited in resolving system and infrastructure complexities in the field of manufacturing, supply chain management, and national defense.

## B. CONTAINER PORT SIMULATION MODEL (CPSM)

The following provides the makeup and development of the CPSM, a multistage, stochastic simulation model that emulates a portion of the United States' West Coast container shipping industry. The model can be best described as a network of multiple-server queuing systems in which the network nodes are represented by the eight West Coast container seaports introduced in Chapter II.

The model is constructed through a series of interconnected flowchart and data modules populated with attributes, variables, and expressions. In presenting the model, module names within CPSM are presented in *italics*, while intrinsic details about the Arena model, such as the names and values of attributes, variables, and expressions, are embedded in the model files themselves via module descriptions. The Arena model files are available upon request from the author, the advisor, or the second reader.

CPSM (see Appendices A thru E) is voluminous, composed of multiple, stacked, interconnected modules, with different seaports appearing as modules exact in appearance and function, differing only in name. For exposition, modules representing the Port of Seattle are presented.

CPSM is a four-stage simulation model that includes the following components:

## 1. Container Port Simulation Model (CPSM) Stages

### *a. Ship Entity Creation Stage*

In the first stage of CPSM, a container ship entity is created and assigned attributes representing its unique characteristics (see Figure 18).

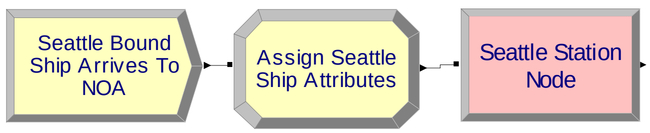


Figure 18. The CPSM Ship Entity Creation Stage consists of 1. a Create Module that creates a ship entity, 2. an Assign Module that assigns the ship a port-of-call and animation properties, and 3. a Station Module that identifies the physical or logical location of the ship at a given time.

The model starting point is a Create Module (*Seattle Bound Ship Arrives to NOA*) that creates a ship and affixes a creation, or interarrival time, to each entity. Per Title 33 Code of Federal Regulations (CFR) all vessels bound for U.S. seaports are required to submit a NOA positional transmission to the National Vessel Movement Center (NVMC), indicating the vessel's intentions, at least 96 hours prior to entry into port (NVMC, 2007). An assumption of our modeling and routing logic is that each interarrival time represents a ship's approach to an imaginary NOA line where each ship transmits a positional transmission to the NVMC. In return, the NVMC provides West Coast seaport status, and if a ship's destination is incapacitated, the NVMC provides the ship with alternative routing options.

The development of interarrival times stems from statistical manipulation of five years of Maritime Administration ship arrival data (MARAD, 2008a). The mean

interarrival time ($\lambda_p$) of a container vessel to the NOA, bound for one of eight West Coast seaports, is calculated per the following formulation with individual port values presented in Table 3:

Given Data [cardinality or units]

| | |
|---|---|
| $d$ | Days in one calendar year [365] |
| $i$ | Year number |
| $n$ | Years of container ship observations [5] |
| $C$ | Container ship port calls [arrivals; total calls] |
| $p$ | Observed port [7] |
| $h$ | Hours in one day [24] |

Statistics [units]

| | |
|---|---|
| $\bar{Y}_p = \bar{X}_p / d$ | Container ship mean daily arrival rate [ships/day] |
| $\bar{X}_p = \sum_{i=1}^{n} C_p / n$ | Container ship mean port calls [calls/year] |

Arrival Rate

| | |
|---|---|
| $\lambda_p = h / \bar{Y}_p$ | Container ship mean interarrival time to NOA line [hours] |

| Port of Interest | Container Vessel Mean Port Calls ($\bar{X}_p$) | Container Vessel Mean Daily Arrival Rate (Arrivals/Day) ($\bar{Y}_p$) | Container Vessel Mean Interarrival Time ($\lambda_p$) |
|---|---|---|---|
| **(1) Seattle, WA** | 769 | 2.11 | 11.40 |
| **(2) Tacoma, WA** | 570 | 1.56 | 15.38 |
| **(3) Portland, OR** | 139 | 0.38 | 63.11 |
| **(4) Oakland, CA** | 1,926 | 5.28 | 4.55 |
| **(5) Los Angeles, CA** | 1,108 | 3.03 | 7.91 |
| **(6) Long Beach, CA** | 1,846 | 5.06 | 4.75 |
| **(7) San Diego, CA** | 42 | 0.12 | 175.20 |

Table 3. Mean port calls, daily arrival rates, and interarrival times for container vessels bound for West Coast seaports of our research. A Seattle bound vessel arrives to the NOA, on average, every 11.40 hours (MARAD, 2008a).

Within CPSM, $\lambda_p$ values are used as means of exponential distributions, which are applicable to this type of research. The exponential distribution is frequently

used as a model for the distribution of times between the occurrence of successive events, such as customers arriving at a service facility or calls coming in to a switchboard (Devore, 2004).

The ensuing Assign Module (*Assign Seattle Ship Attributes*) assigns multiple attributes and animation pictures to entities. Here, each ship is assigned a port-of-call and a graphic representation (ship picture) for use in model animation. The stage's final module, a Station Module (*Seattle Station Node*) defines the physical or logical location of the ship. Here, that location is represented by a 96-hour western alignment with a port-of-call (see Figure 19). The above logic is repeated independently for each port, with appropriate adjustments made for parameter values and other attributes, as described in Table 3.

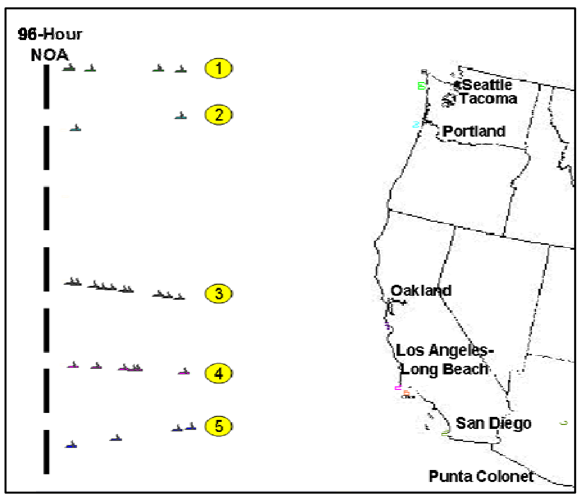


Figure 19. CPSM animation snapshot within Arena. Here, ships bound for 1. Seattle, 2. Tacoma, 3. Oakland, 4. Los Angeles, and 5. Long Beach transit the 96-hour NOA line and approach a port-of-call. The average separation between each vessel is indicative of each port's random ship interarrival time; a lower value (higher arrival rate) narrows the gap between ships.

#### *b. Port Routing Logic Stage*

The second stage of CPSM details our seaport routing logic in case a ship needs to choose an alternate destination subsequent to a TSI. This stage is presented by three substages (see Figure 20).

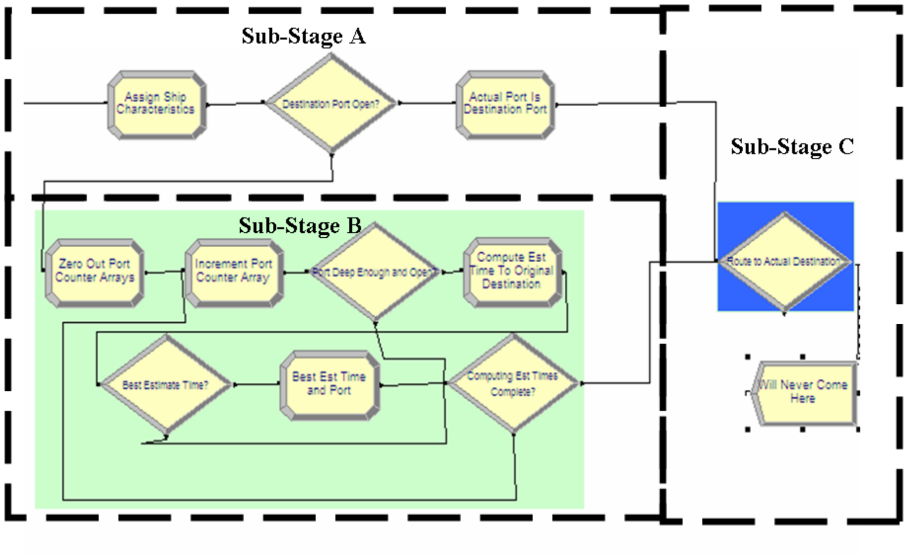


Figure 20. Three substages of the Port Routing Logic Stage within CPSM are each shown in a dashed box. Substage A checks the operational status of seaports, Substage B provides routing logic for diverted vessels and Substage C aligns each ship with an assigned port.

1) Port Routing Logic Substage A. An Assign Module (*Assign Ship Characteristics*) initiates the stage and assigns each ship entity an arrival time to system, draft, and container load. This arrival time is the simulation time at which the ship begins transiting the model. The draft attribute assigned to each entity is consistent with that of the Panamax class container ship identified in Chapter II (41 feet). Ship draft is critical in our port-routing logic; if a ship entity is forced to divert, a vessel's draft must be substantially less than the destination seaport channel draft. Each ship's container load, $\lambda_{ctn}$, is developed through the manipulation of five years of container throughput data (MARAD, 2008b) at our eight ports of research per the following formulation. Individual port values are presented in Table 4.

Statistics [units]

$\overline{T}_{ctn}$ Port mean import containers handled [containers/year]

$\overline{X}_p$ Container vessel mean port calls [calls/year]

Container Content

$\lambda_{ctn} = \overline{T}_{ctn} / \overline{X}_p$ Mean container load [containers/vessel]

| Port of Interest | Container Vessel Mean Port Calls (Calls/Year) (2002-2006) $\overline{X}_p$ | Mean Import Containers Handled (TEUs/Year) (2002-2006) $\overline{T}_{ctn}$ | Container Vessel Mean Container Load (TEUs/Vessel) $\lambda_{ctn}$ |
|---|---|---|---|
| **(1) Seattle, WA** | 769 | 668,594 | 870 |
| **(2) Tacoma, WA** | 570 | 643,447 | 1,130 |
| **(3) Portland, OR** | 139 | 65,013 | 468 |
| **(4) Oakland, CA** | 1,926 | 638,463 | 331 |
| **(5) Los Angeles, CA** | 1,108 | 3,783,317 | 3,416 |
| **(6) Long Beach, CA** | 1,846 | 2,978,756 | 1,614 |
| **(7) San Diego, CA** | 42 | 45,260 | 905 |

Table 4. Mean annual ship port calls, import containers handled, and mean container loads for vessels bound for West Coast ports. Ships bound for Seattle, on average, carry 870 TEUs (MARAD, 2008b).

We generate each container load value ($\lambda_{ctn}$) from a triangular distribution because such distributions are common when minimum, maximum, and modal (most likely) values may be reasonably specified, and when we lack detailed observed data to which distributions could otherwise be fit (Ross, 1998).

The Decide Module, *Destination Port Open?*, senses whether the destination port is open. An operational seaport ("true") indication enables the ship entity to proceed to the Assign Module (*Actual Port Is Destination Port*), which directs each ship to an originally-intended destination, while a "false" indication diverts the ship into the port routing logic (Substage B).

The following section presents Substage B of CPSM's Port Routing Logic Stage that checks the operational status of adjacent ports, channel draft,

queue length, port-to-port distances, and service times in choosing the optimal port for a diverted ship (see Figure 21).

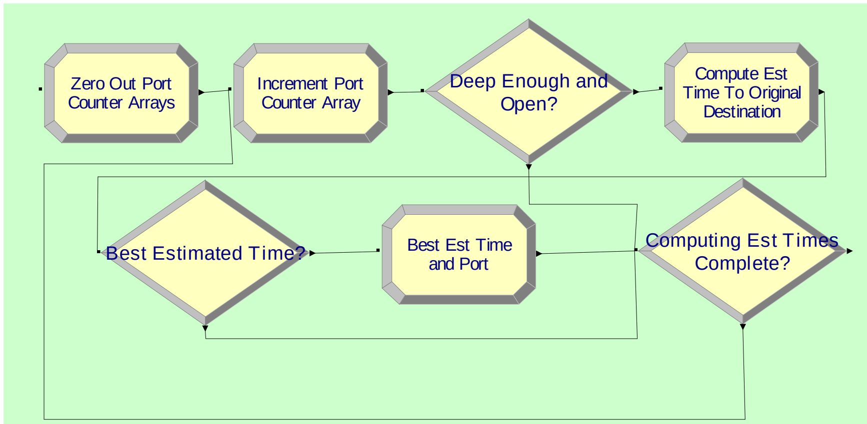


Figure 21. CPSM Port Routing Logic Substage B consisting of various Assign and Decision Modules.

2) Port Routing Logic Substage B. Substage B represents the operational decision of a ship operator subsequent to a TSI and the congestion or incapacitation of a port. Here, modeling logic checks the operational status, channel draft, queue length, proximity, and service time of adjacent West Coast ports in choosing an optimal port for a diverted ship. Diverted vessels respond to a combination of distance and existing port congestion, both of which translate into greater time delays and, thus, greater costs. These additional operating costs for Panamax class carriers are discussed in CPSM's ensuing stage, the Terminal Processing Stage. Note that each ship entity comes through this same logic, regardless of bound port, as it is general enough not to require separate copies for each bound port.

3) Port Routing Logic Substage C. In this substage, the Decide Module, *Route to Actual Destination*, aligns each ship with its original destination or a seaport assigned by model routing logic. The Dispose Module is *intended* as the ending point for entities in a simulation model; however, here this module is an error trap in case of a programming error (see Figure 22).

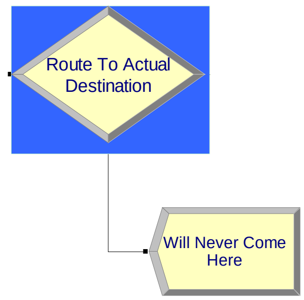


Figure 22. CPSM Port Routing Logic Substage C consisting of a Decide Module that directs each ship to its originally intended or logic-assigned port-of-call. The Dispose Module serves as a relief valve for faulty model logic.

#### c. *Terminal Processing Stage*

The third main stage of CPSM, the Terminal Processing Stage, represents the ship berthing and container yard operations of our model. This stage is presented in three substages.

##### 1) Terminal Processing Substage A

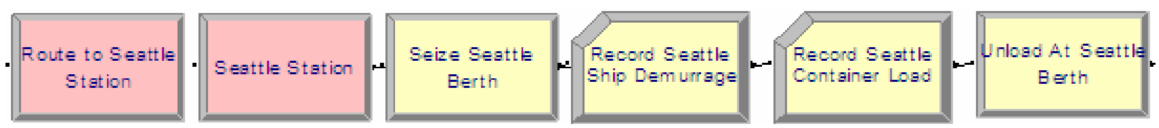


Figure 23. CPSM Terminal Processing Substage A that simulates ship berthing and container offloading. The incremental operating costs and load values of each ship are recorded in this substage.

Here, a ship first traverses a Route Module (*Route to Seattle Station*), which calculates the route time to a port-of-call. For nondiverted ships we assume the ship's position at the NOA to be due west of the original intended port. This route time is simply 96 hours; on the other hand, a diverted ship's route time is computed via basic planar geometry.

A Station Module (*Seattle Port Station*) follows that defines each ship's logical position within the model. Here, the ship is entering port and the Seize Module (*Seize Seattle Berth*) allocates a berth to the ship. If no berth is available, the ship joins a queue. The ensuing Record Module (*Record Seattle Ship Demurrage*) is used to collect each ship's total incremental operating costs of steaming and anchorage

times, or demurrage. In commercial shipping, ship demurrage is the time cost of ownership, and an ancillary cost that represents here liquidated damages for delays in shipments, in particular when a vessel is prevented from loading or discharging cargo within a contracted time. Here, we model ship demurrage as the daily operating costs of a 20-year old, 35,000 DWT Panamax vessel as $50,000 while underway and $32,000 at anchorage, respectively. These figures depict a break-even, voyage-time charter rate and do not include profit, fuel costs, and insurance, and is independent of the container cargo value the vessel carries (Mashagbeh, 2008). Similarly, in the ensuing stages, we model the effects of container demurrage, or those costs incurred to a carrier when a cargo container sits frustrated at a destination port beyond the port allowed free demurrage time (a given number of days) as stipulated in individual port tariff documents.

The subsequent Record Module (R*ecord Container Load)* records the aggregate container load values for all ships and the final module of this substage, a Delay Module (*Unload at Port Berth*), functions as the service time ($\lambda_s$) for a container ship at berth. Modeling crane productivity depends upon a number of factors including the number and type of cranes servicing a ship, the capabilities of the operator(s), stowage patterns, and the location of the crane within the layout of the terminal (i.e., pierside or onboard). Data collection at the Port of Oakland's Ben E. Nutter Terminal enable us to model a single container crane lifting capability (27-30 TEU lifts per hour) as having a Uniform Distribution between 1/30 and 1/27, or Uniform (a = 1/30,b = 1/27). For such a Uniform Distribution, the expected container lifts per hour, $\mu$ is computed as $\mu = \frac{a+b}{2} = \frac{1/30 + 1/27}{2}$ and the standard deviation of the number of lifts per hour, $\sigma$, is $\sigma = \sqrt{\frac{(b-a)^2}{12}} = \sqrt{\frac{(1/30 - 1/27)^2}{12}}$ (Devore, 2004). Applying the Central Limit Theorem, which is appropriate because the number of containers on a ship is typically in the thousands, the total amount of time to offload a container vessel has approximately a Normal Distribution with a mean (container load*$\mu$) and a standard deviation ($\sqrt{\text{container load}} * \sigma$). Port service times applied within CPSM are identified in Table 5.

| Port of Interest | Container Vessel Mean Container Load $\lambda_{ctn}$ | Container Vessel Service Time (Hours) $\lambda_s$ $(\mu, \sigma)$ |
|---|---:|---:|
| **(1) Seattle, WA** | 870 | 30.61, 0.93 |
| **(2) Tacoma, WA** | 1,130 | 39.76, 1.21 |
| **(3) Portland, OR** | 468 | 16.47, 0.50 |
| **(4) Oakland, CA** | 331 | 11.65, 0.35 |
| **(5) Los Angeles, CA** | 3,416 | 120.19, 3.65 |
| **(6) Long Beach, CA** | 1,614 | 56.79, 1.73 |
| **(7) San Diego, CA** | 905 | 31.84, 0.97 |

Table 5. Port service times for container vessels. The service times are expressed as the mean and standard deviation of a Normal Distribution ($\mu$, $\sigma$). On average, a Seattle ship will be serviced in 30.61 hours, with a standard deviation of 0.93 hours.

The following section presents Substage B of CPSM's Terminal Processing Stage (see Figure 24). This substage simulates the movement of containers from pier to terminal container yard.

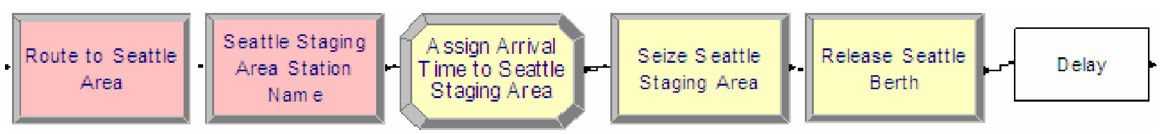


Figure 24. CPSM Terminal Processing Substage B consisting of various modules (i.e., Route, Assign, Seize, Release, and Delay) used to simulate the transfer of container cargo to container yards.

2) Terminal Processing Substage B. In this substage, a ship initially encounters a Route Module (*Route to Seattle Area*) that simulates the container load routing from pierside to a staging area within the terminal container yard by container-handling equipment such as "top pickers" and yard "hustlers" (see Figures 25 and 26).

Figure 25. This picture shows a "top picker" releasing a container onto a yard truck or "hustler" at the Port of Oakland in March 2008.

Figure 26. This picture shows a yard truck or "hustler" used to transport containers throughout container and intermodal yards at the Port of Oakland in March 2008.

The Station Module (*Seattle Staging Area Station Name*) defines a container load's position within a container yard, while the ensuing Assign Module (*Assign Arrival Time to Seattle Staging Area*) marks the load's arrival time to the container yard and is used downstream in the logic to determine container demurrage. The Assign Module also modifies the entity's avatar (for simulation animation) from a ship to a container.

The Seize Module (*Seize Seattle Staging Area*) allocates a resource, here a partition of the existing capacity of the seaport terminal container yard. Pinpointing an actual "box in the yard" capacity for the eight ports and 36 terminals proved problematic because the terminal operators are not sure of this capacity. In addition, it is difficult to model actual "box counts" for seaport terminals from satellite

imagery because port regulations and safety issues govern "how many high" containers may be stacked. Figure 27 illustrates containers stacked "four high" at the Port of Oakland.


Figure 27. This picture shows containers stacked "four high" with a "hustler" in the foreground at the Port of Oakland in March 2008.

The stevedoring company for the Port of Oakland's Hanjin Terminal, Total Terminals Inc., provided a 14,000-TEU capacity approximation for their 120-acre facility (D'Silva, 2008). Using a simple linear equation pairing Hanjin values against the remaining 35 terminals of this study, an approximate TEU capacity has been developed through the following formulation with accompanying seaport capacity approximations listed in Table 6.

<u>Given Data [units]</u>

| | |
|---|---|
| $a$ | Terminal 1 container capacity [TEUs] |
| $b$ | Terminal 1 container yard area [acres] |
| $c$ | Terminal 2 container capacity [TEUs] |
| $d$ | Terminal 2 container yard area [acres] |

<u>Proportional Estimate</u>

$$\frac{a}{b} = \frac{c}{d}$$

| Port | Container Terminals | Terminal Container Yard Acreage (Acres) | Terminal Total TEU Capacity (TEUs) |
|---|---|---|---|
| **(1) Seattle** | 4 | 501 | 58,450 |
| **(2) Tacoma** | 6 | 536 | 62,533 |
| **(3) Portland** | 1 | 200 | 23,333 |
| **(4) Oakland** | 9 | 759 | 88,585 |
| **(5) Los Angeles** | 8 | 1,686 | 196,700 |
| **(6) Long Beach** | 7 | 1,284 | 149,800 |
| **(7) San Diego** | 1 | 25 | 2,917 |
| **(8) Punta Colonet** | 1 | 2,970 | 346,500 |

Table 6. Estimated container capacities of seaports included in this study. The estimated cumulative container capacity of Seattle's four container terminals (Terminals 5, 18, 25, and 46) is 58,450 TEUs.

The Release Module (*Release Seattle Berth*) represents the completion of a ship's service time and subsequently releases a ship from the assigned berth. The final module of the substage, a Delay Module, delays cargo by an amount of time representative of the delay before it is moved out of the container yard by truck.

The following section presents Substage C of CPSM's Terminal Processing Stage which simulates the movement of containers to trucks (see Figure 28).

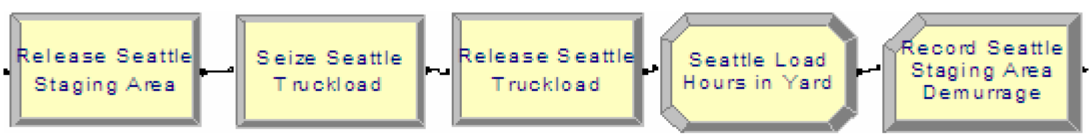


Figure 28. CPSM Terminal Processing Stage Substage C consisting of Release, Seize, Assign, and Record Modules. This stage simulates the transfer of containers from terminal container yard to truck. Incremental container demurrage fees are calculated in this substage.

3) Terminal Processing Sub-Stage C. The Release Module (*Release Seattle Staging Area*) initiates this substage and simulates the release of a container load to a truck. This is a broad assumption area of our modeling because normal terminal operations will release only individual containers to consignees. Additionally, we model the trucking of containers from seaports and exclude rail transport. The ensuing Assign Module, *Seattle Load Hours in Yard,* calculates the total

time a container load sits frustrated in a container yard and the final module of the substage is a Record Module (*Record Seattle Staging Area Demurrage*) that calculates container yard demurrage costs to ship owners and their cargo based upon individual seaport port tariff documents. We model a "door-to-door" contract in which the ocean carrier is responsible for all cargo movement and associated fees related to the transport (and possible delays) of shipment to the consignee. We assume "force majeure" does not exist and port Executive Directors will not extend the allowable free demurrage time that cargo may occupy terminal space. By these assumptions, our goal is to identify the incremental costs suffered by ocean carriers from frustrated cargo subsequent to a TSI.

### *d. Landside Routing Logic Stage*

The final stage of CPSM emulates cargo routing from port terminals to metropolitan areas throughout the United States. This stage is presented in three substages (see Figure 29).

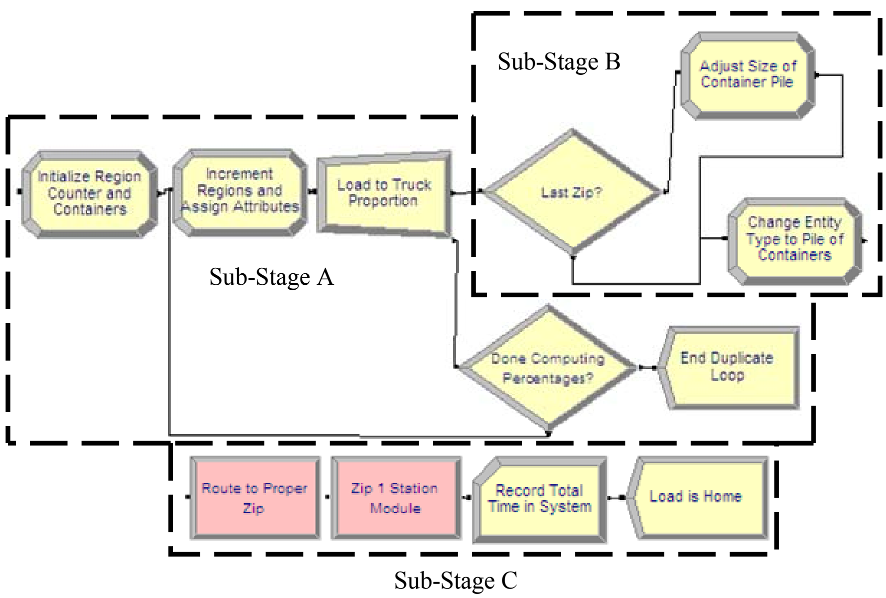


Figure 29. Three CPSM Landside Routing Logic Substages, each denoted with a dashed box. Substage A proportionally allocates each container load to U.S. metropolitan areas based upon population density, Substage B checks truck routing to each zip code, and Substage C routes each container load to a final destination and records the total time in port.

1) Landside Routing Logic Substage A. In this substage, container loads are proportionally allocated to one-digit zip codes throughout the United States based upon population densities. For states comprising each one-digit zip code (see Figure 30), estimated populations were compiled and ranked in accordance with Table 7.

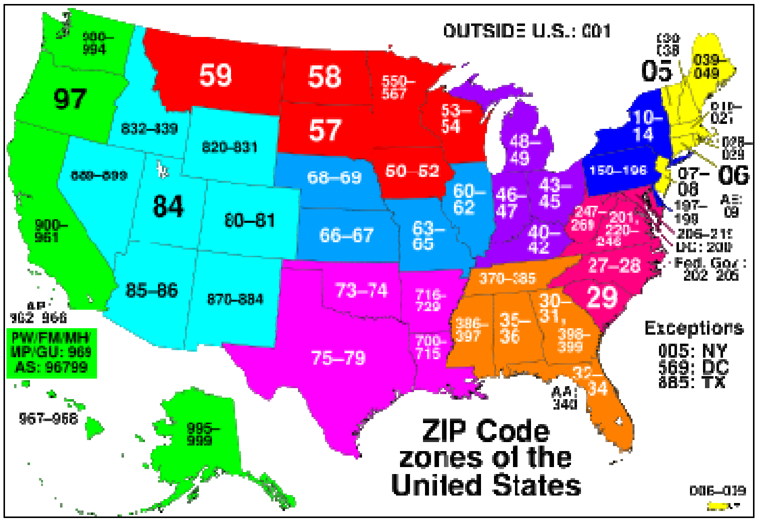


Figure 30. Zip code regions of the United States. Population densities for each one-digit region are used to proportionally allocate West Coast container loads. New England states comprise Zip Code 0 (From: USCB, 2008).

| Population Rank | Zip Code Region | U.S. Population Estimate (July 2007) | U.S. Population Percentage (July 2007) |
|---|---|---|---|
| 1 | 9 | 48,735,960 | 15.95 |
| 2 | 3 | 41,499,348 | 13.58 |
| 3 | 7 | 34,649,697 | 11.34 |
| 4 | 1 | 32,595,285 | 10.67 |
| 5 | 4 | 32,125,502 | 10.51 |
| 6 | 2 | 29,199,503 | 9.56 |
| 7 | 0 | 26,891,564 | 8.80 |
| 8 | 6 | 23,281,531 | 7.62 |
| 9 | 8 | 20,403,129 | 6.68 |
| 10 | 5 | 16,181,097 | 5.30 |
| | | | |
| | **TOTAL** | 305,562,616 | 100.00 |

Table 7. United States one-digit zip code population rankings. States comprising Zip Code 9 maintain the largest population density and are allocated the greatest proportion of each container load within the CPSM. For example, 15.95 percent of a 4,000-TEU container load, or 638 containers, would be routed to Zip Code 9 (After: Demographia, 2008).

The following section presents Substage B of CPSM's Landside Routing Logic Stage that proportionally allocates each container load to landside transport (see Figure 31).

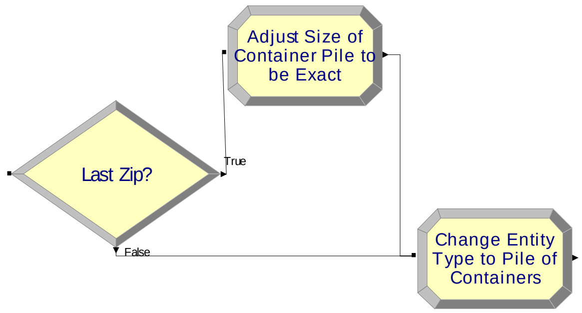


Figure 31. CPSM Landside Routing Logic Substage B consisting of a Decide Module and two Assign Modules. This substage ensures each container load is proportioned to each one-digit zip code and changes the avatar of the entity from that of a container to a truck.

2) Landside Routing Logic Sub-Stage B. The Decide (*Last Zip?*) and Assign Module (*Adjust Size of Container Pile to Be Exact*) checks to ensure each container load has been proportionally divided to the ten different zip codes of the United States. The remaining Assign Module (*Change Entity Type to Pile of Containers*) modifies the entity's avatar (for simulation animation) from a container into a truck.

The following section presents Substage C of CPSM's Landside Routing Logic Stage that routes cargo to final U.S. destinations (see Figure 32).

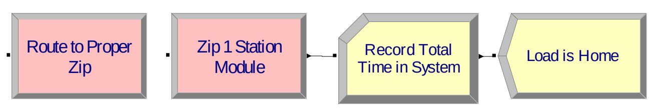


Figure 32. CPSM Landside Routing Stage Substage C consisting of Route, Station, Record, and Dispose Modules. This substage routes each truck to a final destination and records the container's total time in port.

3) Landside Routing Logic Sub-Stage C. In this final substage of CPSM, the module *Route to Proper Zip* routes each truck entity to a metropolitan area (*Zip 1 Station Module*) of the United States (see Figure 33).

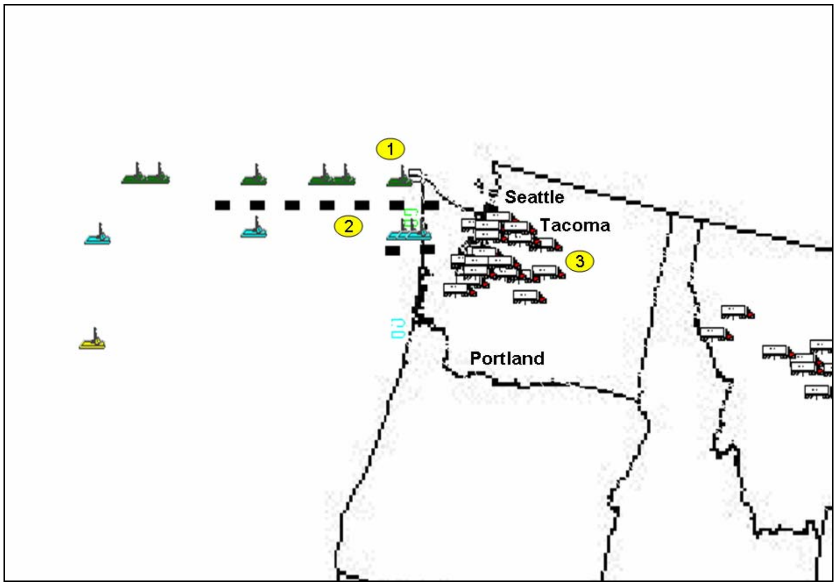


Figure 33. Snapshot of the landside animation within CPSM. Here, as 1. ships arrive into Seattle, 2. containers are offloaded and accumulate in the port's container yard. Containers are then 3. trucked to metropolitan areas throughout the United States.

The final two modules of CPSM include a Record Module (*Record Total Time in System*) and a Dispose Module (*Load is Home*). The Record Module records each passing entity's total time in port and the Dispose Module, *Load is Home*, functions as the ending point for the simulation entities.

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# IV. SCENARIO, ANALYSIS AND RESULTS

## A. SCENARIOS FOR RESEARCH

A maritime infrastructure risk assessment scale developed by ABS Consulting of Knoxville, Tennessee, aids our scenario development (Hanson, 2008). The Maritime Security Risk Assessment Model (MSRAM) is a derivation of various Department of Homeland Security (DHS) and U.S. Coast Guard (USCG) maritime security directives and categorizes the potential impact of a TSI upon port operations, the civilian populace, and local and national economies (see Figure 34). We use this scale to determine the time interval each of our hypothesized TSI events affects the MTS.

| Types | CAT 2 | CAT 3 | CAT 4 | CAT 5 | CAT 6 | CAT 7 |
|---|---|---|---|---|---|---|
| Disruption of Port Commerce | Interruption of operations for 4 to 7 days | Interruption of operations for 8 to 15 days | Interruption of operations for 16 to 45 days | Interruption of operations for 46 to 120 days | Interruption of operations For more Than 121 days | |
| Public safety and health | | 10 to 99 deaths | 100 to 999 deaths | 1,000 to 9,999 deaths | 10,000 to 99,999 deaths | > 100,00 deaths |

| Amount of Commerce Affected | | | | |
|---|---|---|---|---|
| NONE | LOW | MEDIUM | HIGH | VERY HIGH |
| 0% | 1 to 25% | 26 to 50% | 51 to 75% | 76 to 100% |

Figure 34. The Maritime Security Risk Assessment Model (MSRAM) provides a scale to estimate the time interval a TSI affects the MTS. For instance, a Category 2 incident can potentially disrupt a port's operations from 4 to 7 days and affect up to 25 percent of the port's commerce (From: Hanson, 2008).

### 1. Baseline Model – Normal Operations

We first model "normal operations" of the West Coast shipping industry to establish baseline statistics to which we may compare abnormal scenarios. The baseline run represents the eight seaports introduced in Chapter II and their associated intermodal assets (i.e., berthing, container yard space, and trucking). From time-series plots of key

output variables, we decided one month is an appropriate warm-up period for our model, so we base all our observations on the following 11 months of operations.

### 2. Isolated Incident: Ports of Los Angeles (POLA) and Long Beach (POLB)

We model an isolated incident affecting the neighboring Ports of Los Angeles and Long Beach. The remaining West Coast seaports remain fully operational. The incident, a security breach, earthquake, or any other naturally-occurring or human-caused event of significance, incapacitates both seaports (berths, container yards, and trucking) for a period of two weeks, bringing port operations to a standstill. After one-month's time from the onset of the incident, both ports gradually recover to full operational capability (i.e., 100 percent of berths, container yards, and intermodal operations are functionally restored). Per the MSRAM, this incident is modeled as CAT 4.

### 3. Oakland Earthquake

We simulate a 7.2 earthquake in the vicinity of the Port of Oakland. Centered near Interstate-880 (I-880) and the Nimitz Freeway, the incident incapacitates the seaport for two weeks, then full operational capability is gradually recovered after one-month's time from the onset of the earthquake (i.e., 100 percent of berths, container yards, and intermodal operations are functionally restored). The remaining West Coast seaports remain fully operational. Per the MSRAM, we categorize the Oakland earthquake as CAT 4.

### 4. Reduced Resource: Transportation Worker Identification Credential (TWIC)

The TWIC is a common identification card initiative for all personnel allowed unescorted access to secure areas of marine facilities and vessels (TSA, 2008). Promulgated by the Maritime Transportation Security Act of 2002 and administered by USCG and the Transportation Security Administration (TSA), an estimated one million national seaport workers, including merchant mariners, port facility employees, longshoremen, and truck drivers, will be required to carry this "Smart Card." We model a single West Coast compliance date. The inability of a significant amount of personnel

to obtain the TWIC (Aitoro, 2008), coupled with stringent compliance date marshalling, results in a 25 percent resource (i.e., manpower, ship berthing, container handling, and trucking) reduction at all West Coast ports for two weeks. After the two-week period, 100 percent of West Coast seaport personnel possess the required identification (or the requirement is further delayed). Per the MSRAM, this incident is modeled as CAT 3.

### 5. International Longshoremen and Warehousemen's Union (ILWU) Lockout

In September 2002, the PMA, representative of 72 ocean cargo carriers, terminal operators, and stevedoring companies of the West Coast shipping industry, locked longshoremen, dockworkers, and marine clerks out of terminals and their jobs in retaliation for an intentional slowdown of labor by the ILWU (see Figure 35). The slowdown resulted from contentions about safety, workforce size, and job security issues that were being exacerbated by increasing automation of terminal cargo-handling operations. The lockout closed West Coast seaports from San Diego to the Canadian border, which handle more than 77 percent of the nation's inbound container cargo from Asia, for 10 days, costing the U.S. economy billions in revenue (White, 2008). The lockout ended when President George W. Bush enacted the Taft-Hartley Act that restricts the activities and power of labor unions in cases of national importance.


Figure 35. International Longshoremen and Warehousemen's Union (ILWU) picketers at the Oakland docks, October 2002. The ILWU lockout lasted 10 days and cost the U.S. economy billions of dollars in revenue (From: Internationalist, 2002).

We model this scenario twice. First, the scenario "ILWU-" is run. The "-" represents the case where West Coast-bound ships cannot call upon the Mexican port of Punta Colonet. The second run, "ILWU+," identifies Punta Colonet as an alternate port for West Coast-bound ocean carriers during the lockout. After the 10-day lockout, all West Coast ports return to full functionality (i.e., 100 percent of berths, container yards, and intermodal operations are operationally restored). Per the MSRAM, these scenarios are modeled as CAT 3 incidents.

## B. RESULTS

Our analysis provides key insights on resource utilization, vessel waiting time, and queue lengths, vessel and container throughput, as well as incremental costs inflicted on ocean carriers subsequent to a TSI. Because our models involve random inputs (i.e., arrival times and service times), the outputs are also random, so it is incumbent upon us to gather statistics on output variability. In pilot runs, we found that making 1,000 independent one-year replications of each scenario, each initialized, warmed-up and stopped in the same way, provides very good precision because of the very small

confidence intervals achieved for our statistics. In the tables we present, we report the mean over the 1,000 replications for each output performance statistic, as well as the half-width of 95 percent confidence intervals on the expected values of these outputs; both of these measures are automatically computed by the Arena simulation software.

### 1. Baseline Model – Normal Operations

#### *a. West Coast Effects*

Under normal conditions, in which ships bound for West Coast ports dock at originally-intended destinations, seaport berths and container yards exhibit relatively low utilization indicative of sufficient capacity. For our simulation, Los Angeles exhibits the highest berth utilization value of 0.53 (e.g., at any instant in time, a berth is occupied with this probability). The closer a utilization value gets to 1.0, the more congested the resource (see Figure 36). However, the current model accounts solely for import

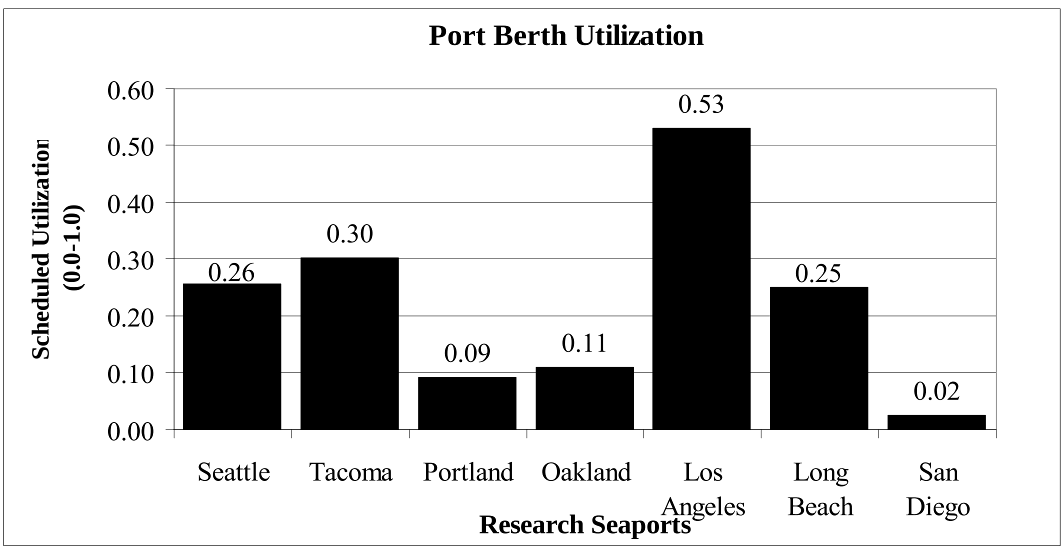


Figure 36. West Coast seaports berth utilization values under normal conditions. The Port of Los Angeles exhibits the highest (0.53).

containers, while in 2006, the movement of export and empty containers accounted for 48.7 percent of container movement along the West Coast (PMA, 2006). We know that some capacity in our model is consumed by loading export and empty containers;

nonetheless, our models and our observations are all under the same assumptions, so comparisons of TSI-afflicted scenarios with this baseline scenario remain valid within these assumptions.

These low-berth and container-yard utilization values induce negligible average waiting times for vessels attempting to berth coastwide (see Table 8). However, even under normal conditions, the West Coast infrastructure is susceptible to sporadic congestion caused by the random arrivals and service times of ships. For example, we observe that a Los Angeles-bound ship will wait 71.48 hours (3 days) for a berth and harbor congestion in San Pedro Bay, at a given time, can produce a 13-ship backlog at Los Angeles (see Table 8 and Figure 37). Harbor congestion is also evident at ports with less seaport infrastructure and traffic intensity such as the Pacific Northwest ports of Seattle, Tacoma, and Portland. This congestion induces minimal incremental operating costs to ocean carriers when we take into consideration the total West Coast ship throughput. For an 11-month simulation, 5,858 West Coast-bound ships accrue a coastwide total of $29,000 in additional operating costs. This equates to less than $5 per ship.

## Scenario: Normal Operations

| Ship Bound For: | Ship Throughput | Ship Operating Costs ($K) | Container Yard Demurrage ($K) | Import Containers (TEUs) | Scheduled Utlization | | | Waiting Time (Hours) | | Queue Length | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average | Average | Average | Average | Average | Min | Max | Average | Max | Average | Max |
| **Long Beach (Berth)** | 1,688 ± 3 | - | | 2,725,347 ± 4,101 | 0.25 ± 0.00 | 0.22 | 0.28 | - | - | - | - |
| **(CY)** | - | - | 119,806 ± 421 | - | 0.14 ± 0.00 | 0.12 | 0.15 | - | - | - | - |
| **Los Angeles (Berth)** | 1,012 ± 2 | 13.68 ± 5.20 | | 3,457,808 ± 6,955 | 0.53 ± 0.00 | 0.46 | 0.60 | 0.01 ± 0.00 | 71.48 | - | 13 |
| **(CY)** | - | - | 151,616 ± 692 | - | 0.13 ± 0.00 | 0.12 | 0.15 | - | - | - | - |
| **Oakland (Berth)** | 1,761 ± 3 | - | - | 583,017 ± 901 | 0.11 ± 0.00 | 0.10 | 0.12 | - | - | - | - |
| **(CY)** | - | - | - | - | 0.07 ± 0.00 | 0.06 | 0.07 | - | - | - | - |
| **Portland (Berth)** | 127.27 ± 0.69 | 3.66 ± 0.55 | - | 59,504 ± 331 | 0.09 ± 0.00 | 0.06 | 0.13 | 0.02 ± 0.00 | 26.72 | - | 3 |
| **(CY)** | - | - | 140.93 ± 2.26 | - | 0.03 ± 0.00 | 0.02 | 0.04 | - | - | - | - |
| **Punta Colonet (Berth)** | - | - | - | - | - | - | - | - | - | - | - |
| **(CY)** | - | - | - | - | - | - | - | - | - | - | - |
| **San Diego (Berth)** | 45.02 ± 0.42 | - | - | 40,689 ± 381 | 0.02 ± 0.00 | 0.01 | 0.04 | - | - | - | - |
| **(CY)** | - | - | 568.97 ± 15.40 | - | 0.17 ± 0.00 | 0.07 | 0.28 | 1.64 ± 0.13 | 197.85 | - | 4 |
| **Seattle (Berth)** | 702.95 ± 1.62 | 0.97 ± 0.52 | - | 611,886 ± 1,437 | 0.26 ± 0.00 | 0.22 | 0.30 | - | 26.59 | - | 6 |
| **(CY)** | - | | 28,059 ± 165 | - | 0.09 ± 0.00 | 0.08 | 0.11 | - | - | - | - |
| **Tacoma (Berth)** | 521.00 ± 1.38 | 10.71 ± 1.59 | | 588,528 ± 1,605 | 0.30 ± 0.00 | 0.24 | 0.36 | 0.02 ± 0.00 | 40.71 | - | 6 |
| **(CY)** | - | - | 9,153 ± 62 | - | 0.07 ± 0.00 | 0.06 | 0.09 | - | - | - | - |
| **Total West Coast (Berth)** | 5,858 | 29.03 ± 5.48 | - | 8,066,782 ± 8,280 | - | - | - | - | - | - | - |
| **(CY)** | - | - | 309,346 ± 823 | - | - | - | - | - | - | - | - |

Note: CY stands for container yard and a cell marked with a hyphen (-) indicates a negligible value.

Table 8. Data output from CPSM Normal Operations scenario. From 1,000 simulations, on average, the Port of Los Angeles received 1,012 container vessels and in excess of 3.4 million imported TEUs. The incremental operating costs incurred by Los Angeles-bound ships are minimal when compared to ship throughput. Despite 0.53 berth utilization, at a given point, a ship bound for Los Angeles is expected to wait 71.48 hours and the port will experience a 13-ship backlog.

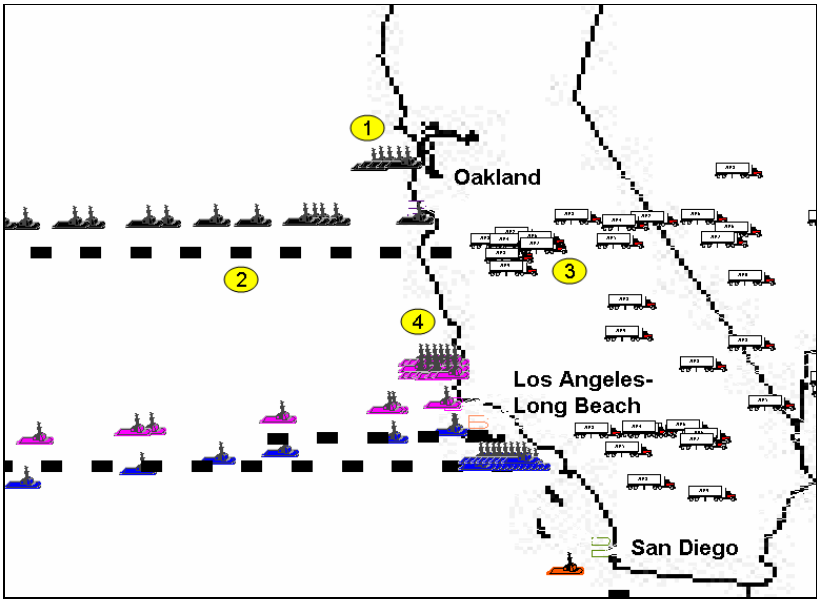


Figure 37. Snapshot from CPSM during normal operations. Sporadic West Coast congestion of 1. ships and 2. containers are shown at Oakland, Los Angeles, and Long Beach. Containers are offloaded and transported from container yards via 3. trucks. A backlog of ships is visible at 4. Los Angeles.

Conversely, low utilization values do not always reflect minimal waiting time and queue lengths. San Diego, although maintaining the smallest container yard and container yard capacity on the West Coast, exhibits the longest average ship-to-container yard transfer (1.64 hours) with a maximum transfer time of 197.85 hours (8 days) (see Table 8). Recall San Diego's mean interarrival time ($\lambda_p$) of 175.20 hours and service time ($\lambda_s$) of 31.84 hours of ships. It appears the port's ability to accommodate additional vessels and cargo is unrealistic, and the harbor is highly susceptible to over-congestion and a bottleneck if tasked to accommodate additional volume subsequent to a West Coast TSI.

Ship and container throughput values for the entire West Coast align with annual values in Chapter III and indicate the consistency of our model. Because of sporadic congestion and wait times, the entire West Coast shipping industry accrues \$309 million in container demurrage fees. In relation to the 8.06 million TEUs transiting the West Coast, this demurrage value equates to roughly \$38 per container. A port-by-port analysis of container throughput indicates ocean carriers are susceptible to suffer at

least one-day container demurrage for frustrated cargo at any West Coast seaport (see Table 9). For example, a port does not assess cargo demurrage fees until a container sits frustrated beyond the port's demurrage free time period, which is normally five days. On the sixth day, a carrier is assessed cargo demurrage fees for the first five days plus an even greater rate for the additional days thereof.

| Ports | Current Port Tariff Demurage Fee ($/TEU/Day) | Normal Ops Demurrage Charged Per TEU ($/TEU/Day) |
|---|---|---|
| **(1) Seattle, WA** | $46.00 | $45.85 |
| **(2) Tacoma, WA** | $17.00 | $15.55 |
| **(3) Portland, OR** | $2.50 | $2.36 |
| **(4) Oakland, CA** | $34.00 | - |
| **(5) Los Angeles, CA** | $43.00 | $43.84 |
| **(6) Long Beach, CA** | $43.00 | $43.95 |
| **(7) San Diego, CA** | $12.60 | $13.98 |

Table 9. The first column shows the published container demurrage fees per current port tariff documents. If a container is unloaded and removed from port stowage within five days, there is no demurrage penalty. However, if the container is frustrated (delayed) six, or more days, the port demurrage fee is charged for the total number of days in storage. For example, a container can spend five days in Seattle for free, but if it stays six days, a demurrage charge of $276.00 is due. The second column shows the average demurrage cost incurred per TEU by ocean carriers bound for West Coast ports. We therefore infer, because of random congestion, that ocean carriers bound for Seattle are likely to pay a single day of container demurrage fees per container. Oakland bound carriers experience negligible congestion and do not incur any additional cargo fees.

## 2. Isolated Incident: Ports of Los Angeles (POLA) and Long Beach (POLB)

### *a. Affected Ports*

Analysis shows incapacitating the Ports of Los Angeles and Long Beach for two weeks will induce significant ship and cargo congestion within San Pedro Bay. We observe that the average delay for ship berthing, at both ports, exceeds 3.60 hours,

with a maximum waiting time surpassing 336 hours (14 days) (see Table 10). Substantial ship and cargo queuing is observed at anchorages and docks—up to 36 ships and 25 (1,614 TEUs) container loads at Long Beach and 23 ships and 28 (3,416 TEUs) container loads at Los Angeles are simulated to await disposition. This congestion reduces ship and container throughput at both ports from vessel diverts; Long Beach's annual volume dips by 72 vessels (4.26 percent) and 115,971 TEUs (4.46 percent), while throughput at Los Angeles is degraded by 41 vessels (3.97 percent) and 136,928 TEUs (4.14 percent) in comparison to baseline figures.

| Scenario: Los Angeles - Long Beach Incident | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Ship Throughput** | **Ship Operating Costs ($K)** | **Container Yard Demurrage ($K)** | **Import Containers (TEUs)** | **Scheduled Utlization** | | | **Waiting Time (Hours)** | | **Queue Length** | |
| ***Ship Bound For:*** | ***Average*** | ***Average*** | ***Average*** | ***Average*** | ***Average*** | ***Min*** | ***Max*** | ***Average*** | ***Max*** | ***Average*** | ***Max*** |
| **Long Beach (Berth)** | 1,616 ± 3 | 7,769 ± 111 | - | 2,608,880 ± 4,125 | 0.26 ± 0.00 | 0.24 | 0.30 | 3.61 ± 0.05 | 336.00 | 0.73 ± 0.01 | 36 |
| **(CY)** | - | - | 157,836 ± 711 | - | 0.14 ± 0.00 | 0.12 | 0.15 | 2.09 ± 0.04 | 335.99 | 0.42 ± 0.01 | 25 |
| **Los Angeles (Berth)** | 971.91 ± 1.98 | 4,672 ± 86 | - | 3,320,494 ± 6,889 | 0.56 ± 0.00 | 0.49 | 0.62 | 3.60 ± 0.07 | 373.25 | 0.44 ± 0.01 | 23 |
| **(CY)** | - | - | 219,247 ± 1,238 | - | 0.13 ± 0.00 | 0.12 | 0.15 | 3.54 ± 0.06 | 335.99 | 0.43 ± 0.01 | 28 |
| **Oakland (Berth)** | 1,761 ± 3 | - | - | 583,147 ± 884 | 0.11 ± 0.00 | 0.09 | 0.12 | - | - | - | - |
| **(CY)** | - | - | - | - | 0.07 ± 0.00 | 0.06 | 0.08 | - | - | - | - |
| **Portland (Berth)** | 127.33 ± 0.69 | 3.41 ± 0.57 | - | 59,481 ± 323 | 0.09 ± 0.00 | 0.06 | 0.13 | 0.02 ± 0.00 | 28.40 | - | 3 |
| **(CY)** | - | - | 140.83 ± 2.20 | - | 0.03 ± 0.00 | 0.02 | 0.04 | - | - | - | - |
| **Punta Colonet (Berth)** | - | - | - | - | - | - | - | - | - | - | - |
| **(CY)** | - | - | - | - | - | - | - | - | - | - | - |
| **San Diego (Berth)** | 25.16 ± 0.25 | 5.33 ± 1.90 | - | 42,944 ± 300 | 0.63 ± 0.00 | 0.62 | 0.65 | 0.93 ± 0.22 | 514.91 | 29.65 ± 0.27 | 92 |
| **(CY)** | - | - | 289.16 ± 18.88 | - | 0.07 ± 0.00 | 0.02 | 0.16 | 3.00 ± 0.35 | 481.09 | 4.87 ± 0.00 | 8 |
| **Seattle (Berth)** | 773.33 ± 1.69 | 6,318 ± 179 | - | 725,860 ± 1,649 | 0.30 ± 0.00 | 0.26 | 0.35 | 8.99 ± 0.34 | 346.11 | 0.87 ± 0.03 | 75 |
| **(CY)** | - | - | 33,432 ± 195 | - | 0.11 ± 0.00 | 0.10 | 0.13 | - | - | - | - |
| **Tacoma (Berth)** | 521.64 ± 1.36 | 12.01 ± 1.85 | - | 589,503 ± 1,582 | 0.30 ± 0.00 | 0.25 | 0.36 | 0.02 ± 0.00 | 47.88 | - | 8 |
| **(CY)** | - | - | 9,169 ± 59 | - | 0.07 ± 0.00 | 0.06 | 0.08 | - | - | - | - |
| **Total West Coast (Berth)** | 5,797 | 18,780 ± 229 | - | 7,930,311 ± 8,283 | - | - | - | - | - | - | - |
| **(CY)** | - | - | 420,113 ± 1,414 | - | - | - | - | - | - | - | - |
| Note: CY stands for container yard and a cell marked with a hyphen (-) indicates a negligible value. | | | | | | | | | | | |

Table 10. Data output from CPSM Los Angeles—Long Beach Incident scenario. Compared to normal West Coast operations, a two-week isolated incident reduces the annual West Coast ship throughput by 1 percent, or 61 ships, and containers by 2 percent, or 136,471 TEUs. Here, the Port of San Diego's berth utilization rises to, on average, 0.63, signifying the terminal's intensified activity. Ocean carriers suffer in excess of $18.7 million in additional operating costs and $420 million in container demurrage fees for frustrated cargo because of congestion caused by the influx of vessel diverts from Los Angeles and Long Beach to other ports.

Ocean carriers that *do* berth at Long Beach, are likely to incur, overall, $7.7 million in additional operating charges, or $4,807 per ship (1,616 total ships), while Los Angeles ships will incur $4.67 million, or $4,806 per ship (971 total ships). Harbor and port congestion also induce container demurrage fees to surge by 34 percent at Los Angeles ($67 million) and 28 percent ($38 million) at Long Beach. The following section clarifies the capability of remaining West Coast infrastructure to accommodate ships and cargo diverted from Los Angeles and Long Beach.

#### *b. West Coast Effects*

Our results show that diverted ships and cargo from Los Angeles and Long Beach impose a significant challenge to the remaining West Coast infrastructure. Surges in berthing delays and queue lengths are evident, as terminal infrastructures strain to accommodate the increased arrival rate of ships (carrying many more TEUs) from Los Angeles and Long Beach. San Diego's infrastructure is overwhelmed, as the port's berth utilization intensifies from 0.25 (normal) to 0.63 (see Table 10 and Figure 38), indicating the increased import activity at their eight container berths. San Diego exhibits the most significant ship-to-berth delays (514 hours or 21 days) and a 92-ship backlog at a given point. Ironically, San Diego's annual vessel throughput falls by 51 percent (45 vessels to 22 vessels) because, similar to all West Coast ports, San Diego is now servicing the TEU-heavy vessels from Los Angeles and Long Beach that generate ship and cargo congestion coastwide. At the end of the 11-month simulation run, scenario-created congestion decreases the annual West Coast ship and container throughput by 1 percent (61 ships) and 2 percent (162,242 TEUs), respectively (i.e., these ships and containers remain stuck in the system at the end of our planning horizon; see Figure 39).

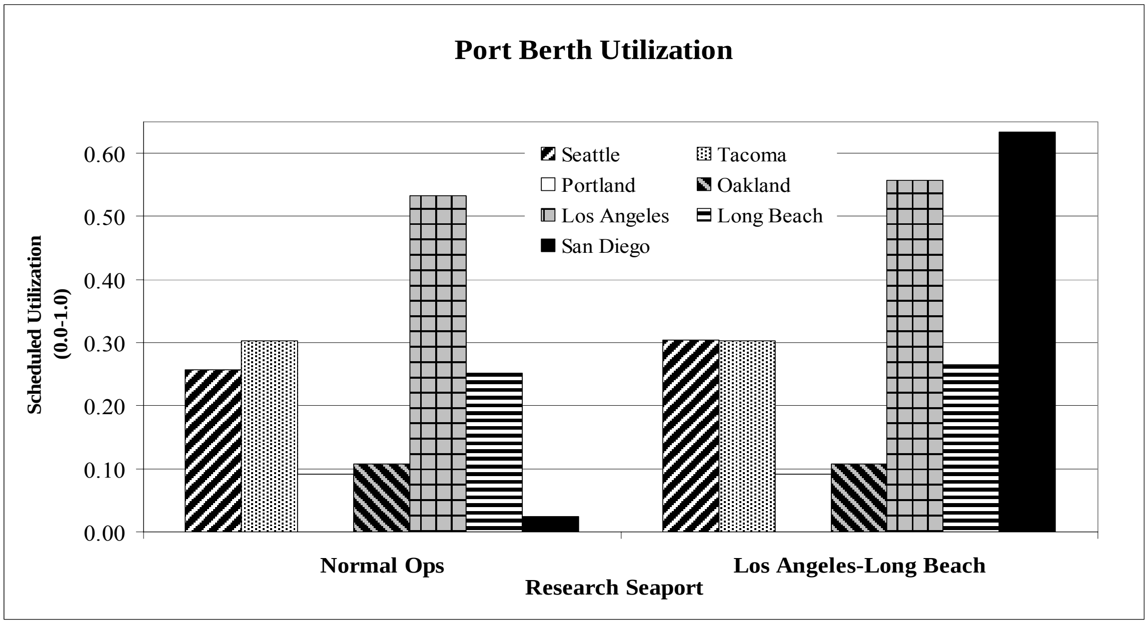


Figure 38. Berth utilization of West Coast ports during normal operations and after an incident affecting the ports of Los Angeles and Long Beach. San Diego's berth utilization (black) value jumps from 0.25 to 0.63, indicating increased activity.

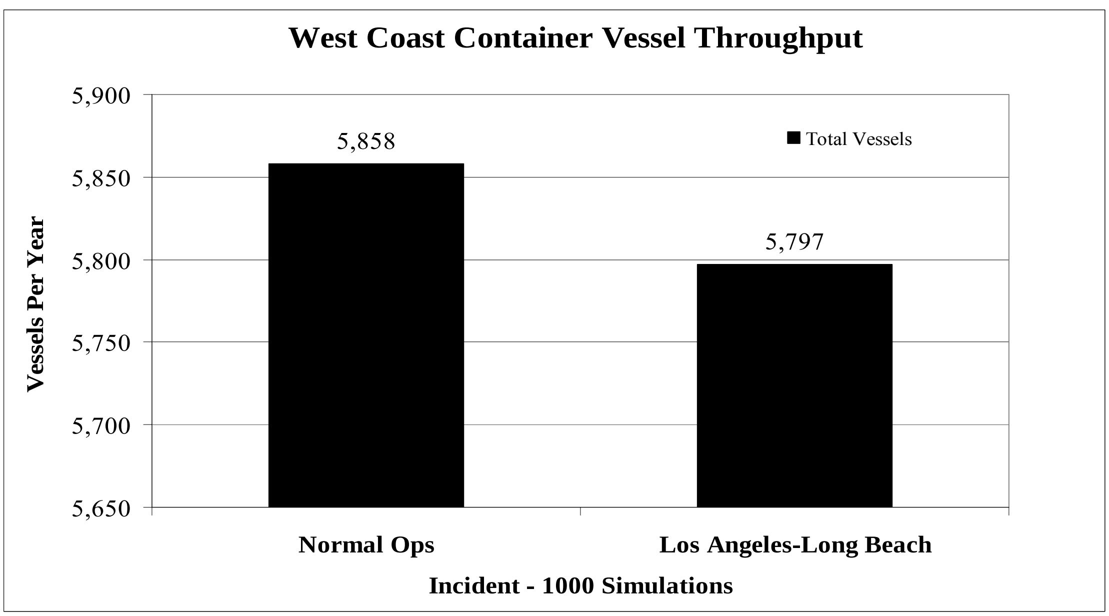


Figure 39. This figure shows a 1 percent (61 vessel) reduction in annual West Coast ship throughput subsequent to an incident incapacitating the ports of Los Angeles and Long Beach for two weeks. Similar analysis for container throughput revealed a 2 percent (162,242 TEUs) decrease in coastal throughput.

The remaining West Coast ports do not have the infrastructure to support the incapacitation of Los Angeles and Long Beach for even a two-week period. Analysis shows a significant decrease in West Coast volume caused by over-congested harbors and incremental operating and cargo storage fees incurred by ocean carriers will exceed $439 million—a significant cost increase. These figures do not reflect the financial impact to local, federal, and global economies nor the associated operating costs of ships and values of cargo stuck in the system at the end of a planning horizon.

### 3. Oakland Earthquake

#### *a. Affected Ports*

Incapacitating the Port of Oakland (terminals and intermodal operations) for a two-week period induces heavy congestion (ship and cargo) throughout the San Francisco Bay area and Oakland Estuary. The average wait time, for nondiverting ships, is observed to exceed 3.72 hours with a maximum delay of 372 hours (15 days) (see Table 11) and, at a given point, a 37-ship backlog and 9 (331 TEUs) container loads are simulated to await disposition. Ship and container volume are observed dipping by 4 percent (72 ships and 23,878 TEUs) and vessels that do call to Oakland (1,689 ships) will accrue in excess of $8.3 million in additional operating costs, or $4,959 per vessel, from congestion. Finally, frustrated cargo demurrage fees will surge $25 million over our baseline figures. The following section clarifies the capability of remaining West Coast infrastructure to accommodate ships and cargo diverted from Oakland.

| Scenario: Oakland Earthquake | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ship Throughput | Ship Operating Costs ($K) | Container Yard Demurrage ($K) | Import Containers (TEUs) | Scheduled Utlization | | | Waiting Time (Hours) | | Queue Length | |
| ***Ship Bound For:*** | ***Average*** | ***Average*** | ***Average*** | ***Average*** | ***Average*** | ***Min*** | ***Max*** | ***Average*** | ***Max*** | ***Average*** | ***Max*** |
| **Long Beach (Berth)** | 1,688 ± 3 | - | - | 2,723,335 ± 4,101 | 0.25 ± 0.00 | 0.22 | 0.28 | - | - | - | - |
| **(CY)** | - | - | 119,746 ± 405 | - | 0.14 ± 0.00 | 0.12 | 0.15 | - | - | - | - |
| **Los Angeles (Berth)** | 1,085 ± 3 | 294.31 ± 5.24 | - | 3,481,347 ± 7,134 | 0.54 ± 0.00 | 0.46 | 0.62 | 0.02 ± 0.00 | 60.47 | - | 19 |
| **(CY)** | - | - | 152,593 ± 683 | - | 0.13 ± 0.00 | 0.11 | 0.15 | - | - | - | - |
| **Oakland (Berth)** | 1,689 ± 3 | 8,377 ± 120 | - | 559,139 ± 874 | 0.11 ± 0.00 | 0.10 | 0.13 | 3.72 ± 0.05 | 336.00 | 0.78 ± 0.01 | 37 |
| **(CY)** | - | - | 25,309 ± 121 | - | 0.08 ± 0.00 | 0.07 | 0.09 | 0.40 ± 0.02 | 336.00 | 0.08 ± 0.00 | 9 |
| **Portland (Berth)** | 127.31 ± 0.71 | 3.70 ± 0.55 | - | 59,557 ± 340 | 0.09 ± 0.00 | 0.06 | 0.14 | 0.02 ± 0.00 | 30.22 | - | 3 |
| **(CY)** | - | - | 139.82 ± 2.18 | - | 0.03 ± 0.00 | 0.02 | 0.04 | - | - | - | - |
| **Punta Colonet (Berth)** | - | - | - | - | - | - | - | - | - | - | - |
| **(CY)** | - | - | - | - | - | - | - | - | - | - | - |
| **San Diego (Berth)** | 45.52 ± 0.42 | - | - | 41,191 ± 382 | 0.03 ± 0.00 | 0.01 | 0.05 | - | - | - | - |
| **(CY)** | - | - | 576.12 ± 16.87 | - | 0.17 ± 0.00 | 0.10 | 0.26 | 1.74 ± 0.14 | 181.44 | 0.01 ± 0.00 | 4 |
| **Seattle (Berth)** | 702.79 ± 1.63 | 0.74 ± 0.42 | - | 611,522 ± 1,471 | 0.26 ± 0.00 | 0.21 | 0.30 | - | 17.48 | - | 4 |
| **(CY)** | - | - | 28,123 ± 161 | - | 0.09 ± 0.00 | 0.08 | 0.11 | - | - | - | - |
| **Tacoma (Berth)** | 521.10 ± 1.41 | 11.6 ± 1.85 | - | 588,777 ± 1,614 | 0.30 ± 0.00 | 0.24 | 0.35 | 0.02 ± 0.00 | 36.90 | - | 6 |
| **(CY)** | - | - | 9,144 ± 60 | - | 0.07 ± 0.00 | 0.06 | 0.09 | - | - | - | - |
| **Total West Coast (Berth)** | 5,858 | 8,687 ± 120 | - | 8,064,870 ± 8,568 | - | - | - | - | - | - | - |
| **(CY)** | - | - | 335,633 ± 810 | - | - | - | - | - | - | - | - |
| | | | | | | | | | | | |
| Note: CY stands for container yard and a cell marked with a hyphen (-) indicates a negligible value. | | | | | | | | | | | |

Table 11. Data output from the CPSM Oakland Earthquake scenario, which incapacitates Oakland for a two-week period. The average delay in berthing Oakland vessels surges to 3.72 hours with a potential delay of 336 hours (14 days), which contributes to an expected 37-ship backlog. As compared to baseline figures, Oakland’s congestion causes a 4 percent (72-ship) reduction in vessel throughput at the port from diverted vessels; however, the remaining West Coast infrastructure can accommodate such a crisis and annual inbound West Coast volume is not affected.

### *b. West Coast Effects*

Results show the existing West Coast infrastructure is able to accommodate an incident incapacitating Oakland for a two-week period (see Figure 40). Los Angeles's substantial supporting infrastructure accommodates the 72 diverted vessels from Oakland with minimal impact to their own routine congestion. Los Angeles is able absorb the Oakland diverts for two reasons—its infrastructure and service time. Los Angeles has a robust infrastructure including berths, container yard capacity, and supporting intermodal resources. Second, despite a ship interarrival time of 4.55 hours, the smaller Oakland ships only carry, on average, 331 TEUs, while Los Angeles is accustomed to servicing Panamax ships carrying, on average, 3,416 TEUs.

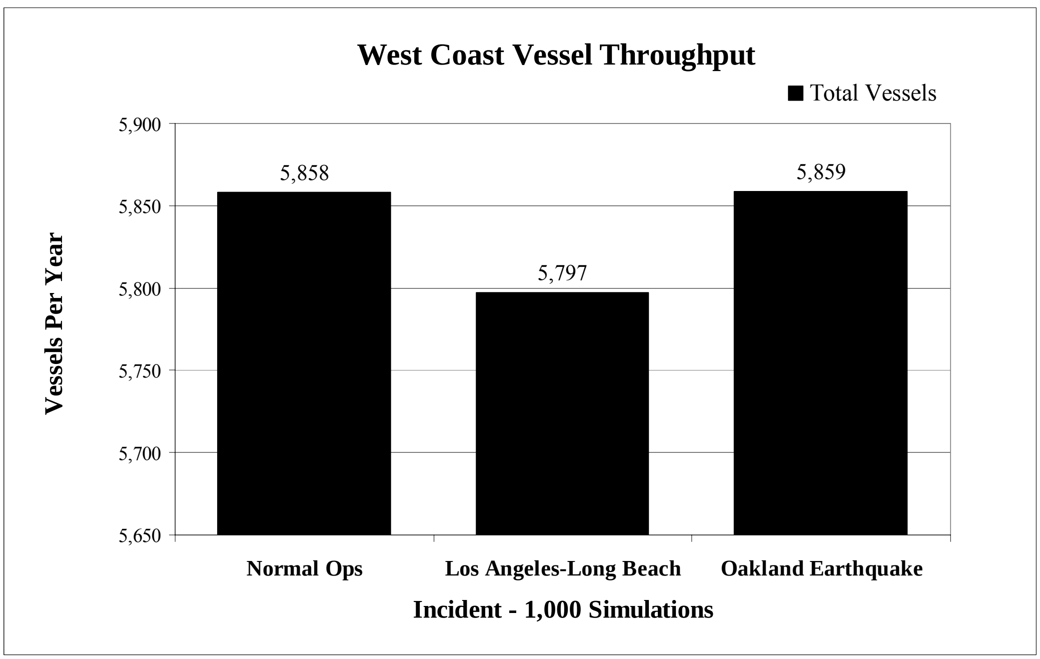


Figure 40. This figure shows the annual West Coast annual ship throughput subsequent to our CPSM modeled Transportation Security Incidents along the West Coast. In comparison to the previous scenario, the remaining West Coast infrastructure can support diverting volume caused by a two-week incapacitation of Oakland. Analysis shows similar results for container throughput.

## 4. Transportation Worker Identification Credential (TWIC)

### *a. West Coast Effects*

Analysis reveals that a two-week, 25-percent reduction in West Coast seaport personnel inflicts minimal impact upon shipping operations. Despite negligible average ship berthing delays, sporadic congestion stems from the random arrival and service times of vessels. For example, at any given time, a ship bound for Los Angeles will be expected to wait up to 119.87 hours, for Portland 41.90 hours, for Seattle 33.52 hours, and for Tacoma 74.50 hours, with backlogs of 21 ships at Los Angeles and six at Seattle and Tacoma, respectively (see Table 12).

| Scenario: TWIC | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Ship Throughput** | **Ship Operating Costs ($K)** | **Container Yard Demurrage ($K)** | **Import Containers (TEUs)** | **Scheduled Utlization** | | | **Waiting Time (Hours)** | | **Queue Length** | |
| ***Ship Bound For:*** | ***Average*** | ***Average*** | ***Average*** | ***Average*** | ***Average*** | ***Min*** | ***Max*** | ***Average*** | ***Max*** | ***Average*** | ***Max*** |
| **Long Beach (Berth)** | 1,685 ± 3 | - | - | 2,720,064 ± 4,198 | 0.26 ± 0.00 | 0.23 | 0.29 | - | - | - | - |
| **(CY)** | - | - | 119,536 ± 419 | - | 0.14 ± 0.00 | 0.13 | 0.15 | - | - | - | - |
| **Los Angeles (Berth)** | 1,013 ± 2 | 178.39 ± 34.86 | - | 3,458,938 ± 6,872 | 0.54 ± 0.00 | 0.48 | 0.63 | 0.13 ± 0.03 | 119.87 | - | 21 |
| **(CY)** | - | - | 151,235 ± 683 | - | 0.13 ± 0.00 | 0.12 | 0.15 | - | - | - | - |
| **Oakland (Berth)** | 1,762 ± 3 | - | - | 583,156 ± 857 | 0.11 ± 0.00 | 0.10 | 0.12 | - | - | - | - |
| **(CY)** | - | - | - | - | 0.07 ± 0.00 | 0.06 | 0.08 | - | - | - | - |
| **Portland (Berth)** | 127.31 ± 0.70 | 7.92 ± 0.98 | - | 59,501 ± 330 | 0.09 ± 0.00 | 0.06 | 0.13 | 0.05 ± 0.01 | 41.90 | - | 3 |
| **(CY)** | - | - | 139.91 ± 2.20 | - | 0.04 ± 0.00 | 0.03 | 0.05 | - | - | - | - |
| **Punta Colonet (Berth)** | - | - | - | - | - | - | - | - | - | - | - |
| **(CY)** | - | - | - | - | - | - | - | - | - | - | - |
| **San Diego (Berth)** | 45.15 ± 0.41 | - | - | 40,818 ± 373 | 0.02 ± 0.00 | 0.01 | 0.04 | - | - | - | - |
| **(CY)** | - | - | 513.35 ± 13.44 | - | 0.04 ± 0.00 | 0.02 | 0.08 | - | - | - | - |
| **Seattle (Berth)** | 702.48 ± 1.73 | 5.83 ± 1.26 | - | 611,114 ± 1,532 | 0.26 ± 0.00 | 0.21 | 0.31 | 0.01 ± 0.00 | 33.52 | - | 6 |
| **(CY)** | - | - | 27,926 ± 166 | - | 0.01 ± 0.00 | 0.08 | 0.11 | - | - | - | - |
| **Tacoma (Berth)** | 521.32 ± 1.41 | 64.77 ± 6.92 | - | 588,935 ± 1,629 | 0.31 ± 0.00 | 0.26 | 0.38 | 0.09 ± 0.01 | 74.50 | - | 10 |
| **(CY)** | - | - | 9,136 ± 62 | - | 0.08 ± 0.00 | 0.06 | 0.09 | - | - | - | - |
| **Total West Coast (Berth)** | 5,856 | 256.91 ± 35.92 | - | 8,062,529 ± 8,423 | - | - | - | - | - | - | - |
| **(CY)** | - | - | 308,488 ± 814 | - | - | - | - | - | - | - | - |
| Note: CY stands for container yard and a cell marked with a hyphen (-) indicates a negligible value. | | | | | | | | | | | |

Table 12. Data output from the CPSM Transportation Worker Identification Credential (TWIC) scenario. A total of 5,856 vessels call upon the West Coast and incur a total of $256,910 in incremental operating costs from sporadic congestion at terminal berths. Coastwide, the average vessel wait time to berth is negligible; however, ships bound for the ports of Los Angeles, Portland, Seattle, and Tacoma, at a given point, will be expected to wait in excess of 33.52 hours.

This congestion degrades annual West Coast ship and container throughput by less than 1 percent (2 ships and 4,253 TEUs) (see Figure 41). Collectively, in comparison to baseline figures, ocean carriers will incur an additional $227,880 (over 5,856 ships) in operating costs, while container yard demurrage fees are not affected.

Existing West Coast infrastructure has the capacity to offset the potential damaging affects from a reduction in support personnel. Volume (i.e., ship and container throughput) and the incremental operating costs to shippers are marginally affected because of sporadic harbor congestion.

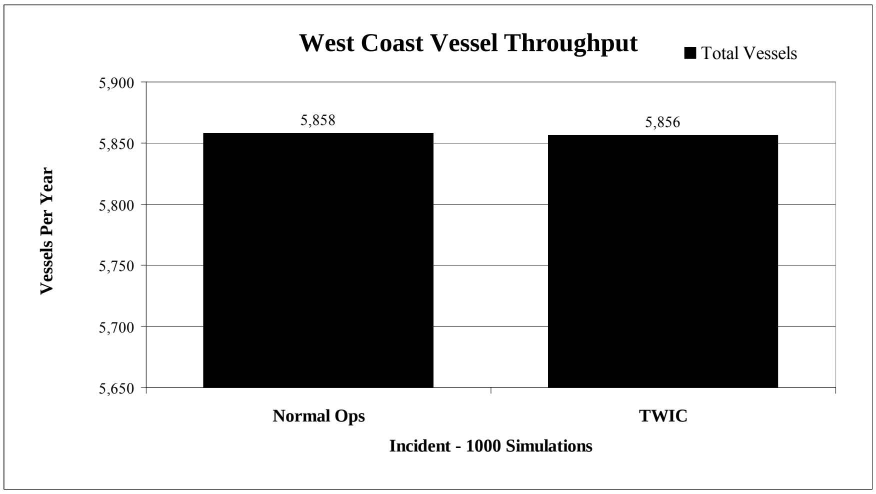


Figure 41. West Coast vessel throughput subsequent to a 25-percent reduction in seaport manning for a period of two weeks. On average, the West Coast volume is degraded by an average of two ships that are absorbed, or stuck in the system, at simulation's end. Similar analysis reveals that container throughput is degraded by an average of 4,253 containers over the course of the simulation.

### 5. International Longshoremen and Warehousemen's Union (ILWU) Lockout

#### *a. West Coast Effects*

Our analysis reveals, with the Mexican port of Punta Colonet inaccessible to shippers (recall ILWU-), the average berthing delays for ships exceed two hours coastwide, with maximum delays exceeding 239 hours or 10 days (see Table 13).

## Scenario: ILWU Lockout (-)

| Ship Bound For: | Ship Throughput | Ship Operating Costs ($K) | Container Yard Demurrage ($K) | Import Containers (TEUs) | Scheduled Utlization | | | Waiting Time (Hours) | | Queue Length | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Average* | *Average* | *Average* | *Average* | *Average* | *Min* | *Max* | *Average* | *Max* | *Average* | *Max* |
| **Long Beach (Berth)** | 1,638 ± 3 | 5,127 ± 73 | - | 2,644,580 ± 4,141 | 0.26 ± 0.00 | 0.23 | 0.28 | 2.35 ± 0.03 | 239.99 | 0.48 ± 0.01 | 38 |
| **(CY)** | - | - | 145,416 ± 593 | - | 0.14 ± 0.00 | 0.13 | 0.15 | 1.35 ± 0.03 | 240.00 | 0.27 ± 0.01 | 28 |
| **Los Angeles (Berth)** | 983.01 ± 1.89 | 3,152 ± 55 | - | 3,357,465 ± 6,530 | 0.54 ± 0.00 | 0.46 | 0.62 | 2.41 ± 0.04 | 240.00 | 0.29 ± 0.01 | 23 |
| **(CY)** | - | - | 191,925 ± 1,008 | - | 0.13 ± 0.00 | 0.12 | 0.15 | 2.07 ± 0.04 | 239.98 | 0.25 ± 0.00 | 28 |
| **Oakland (Berth)** | 1,707 ± 3 | 5,398 ± 71 | - | 565,104 ± 863 | 0.11 ± 0.00 | 0.10 | 0.13 | 2.37 ± 0.03 | 240.00 | 0.51 ± 0.01 | 35 |
| **(CY)** | - | - | 4,109 ± 57 | - | 0.07 ± 0.00 | 0.06 | 0.07 | 0.26 ± 0.01 | 240.00 | 0.05 ± 0.00 | 14 |
| **Portland (Berth)** | 122.82 ± 0.69 | 388.42 ± 19.91 | - | 57,461 ± 333 | 0.09 ± 0.00 | 0.06 | 0.13 | 2.38 ± 0.12 | 243.20 | 0.04 ± 0.00 | 6 |
| **(CY)** | - | - | 156.31 ± 2.49 | - | - | - | - | 0.09 ± 0.03 | 239.91 | - | 2 |
| **Punta Colonet (Berth)** | - | - | - | - | - | - | - | - | - | - | - |
| **(CY)** | - | - | - | - | - | - | - | - | - | - | - |
| **San Diego (Berth)** | 44.47 ± 0.42 | 132.94 ± 11.67 | - | 40,279 ± 383 | 0.02 ± 0.00 | 0.01 | 0.04 | 2.23 ± 0.20 | 239.89 | 0.01 ± 0.00 | 4 |
| **(CY)** | - | - | 649.61 ± 18.30 | - | 0.05 ± 0.00 | 0.02 | 0.08 | 0.17 ± 0.06 | 238.56 | - | 2 |
| **Seattle (Berth)** | 682.67 ± 1.57 | 2,165 ± 47 | - | 593,938 ± 1,389 | 0.26 ± 0.00 | 0.21 | 0.31 | 2.38 ± 0.05 | 239.99 | 0.20 ± 0.00 | 19 |
| **(CY)** | - | - | 33,424 ± 218 | - | 0.09 ± 0.00 | 0.08 | 0.11 | 0.70 ± 0.03 | 240.00 | 0.06 ± 0.00 | 9 |
| **Tacoma (Berth)** | 505.35 ± 1.42 | 1,614 ± 41 | - | 570,865 ± 1,627 | 0.31 ± 0.00 | 0.24 | 0.37 | 2.40 ± 0.06 | 266.35 | 0.15 ± 0.00 | 17 |
| **(CY)** | - | - | 10,308 ± 70 | - | 0.07 ± 0.00 | 0.06 | 0.09 | 0.84 ± 0.04 | 239.99 | 0.09 ± 0.00 | 8 |
| **Total West Coast (Berth)** | 5,684 | 17,978 ± 128 | - | 7,829,694 ± 8,161 | - | - | - | - | - | - | - |
| **(CY)** | - | - | 385,990 ± 1,156 | - | - | - | - | - | - | - | - |

Note: CY stands for container yard and a cell marked with a hyphen (-) indicates a negligible value.

Table 13. Data output from CPSM ILWU Lockout (-) scenario. The Mexican port of Punta Colonet is inaccessible to ships during this scenario. Significant ship and cargo congestion is caused by the 10-day ILWU lockout along the West Coast. The annual West Coast volume dips by 3 percent due to ships still waiting at the end of a planning horizon. The system absorbs the 175 vessels and 237,088 containers not serviced by the model at end of the simulation time. Shippers incur $18 million in additional operating costs and $385 million in cargo storage fees.

We observe heavy coastal congestion to include 38 ships and 28 (1,614 TEUs) container loads that are simulated to await disposition at Long Beach. Additionally, the ports of Long Beach, Los Angeles, and Oakland each suffer 3-percent reductions in annual throughput (Long Beach: 50 ships, 80,767 TEUs, Los Angeles: 29 ships, 100,343 TEUs, and Oakland: 54 ships, 17,913 TEUs), respectively.

As a whole, West Coast ship and container throughput bottlenecks and is degraded by 3 percent (175 ships, 237,088 TEUs; see Figure 42), incremental operating costs incurred by the 5,684 ocean carriers equates to $3,162 per vessel or $17.9 million and cargo demurrage fees increase 22 percent (in comparison to baseline) to $385 million. The total cost incurred to ocean carriers for a 10-day labor union dispute equates to $403 million, the second most significant cost encountered in all of our scenarios.

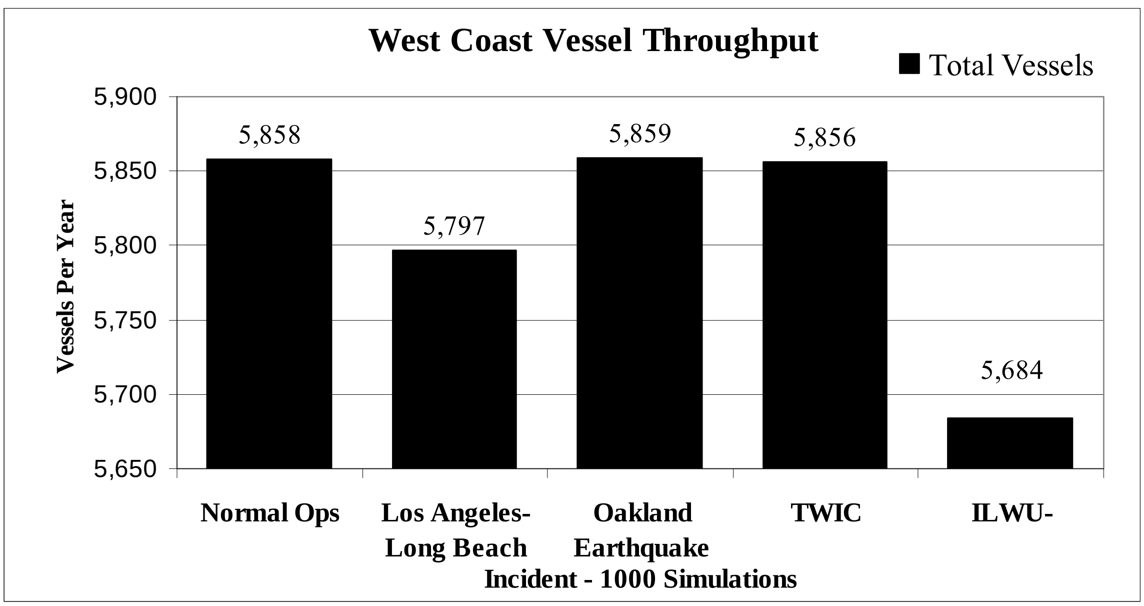


Figure 42. This figure illustrates the effects of our modeled scenarios upon West Coast ship throughput. The ILWU (-) ("-" indicating Punta Colonet is inaccessible to shippers) scenario results in a 3-percent (174 vessels) decrease in annual vessel throughput.

Conversely, with Punta Colonet as an option for shippers (recall, ILWU+), analysis shows that the 175 vessels system previously absorbed by the system (ILWU-) will divert to Punta Colonet (see Figure 43).

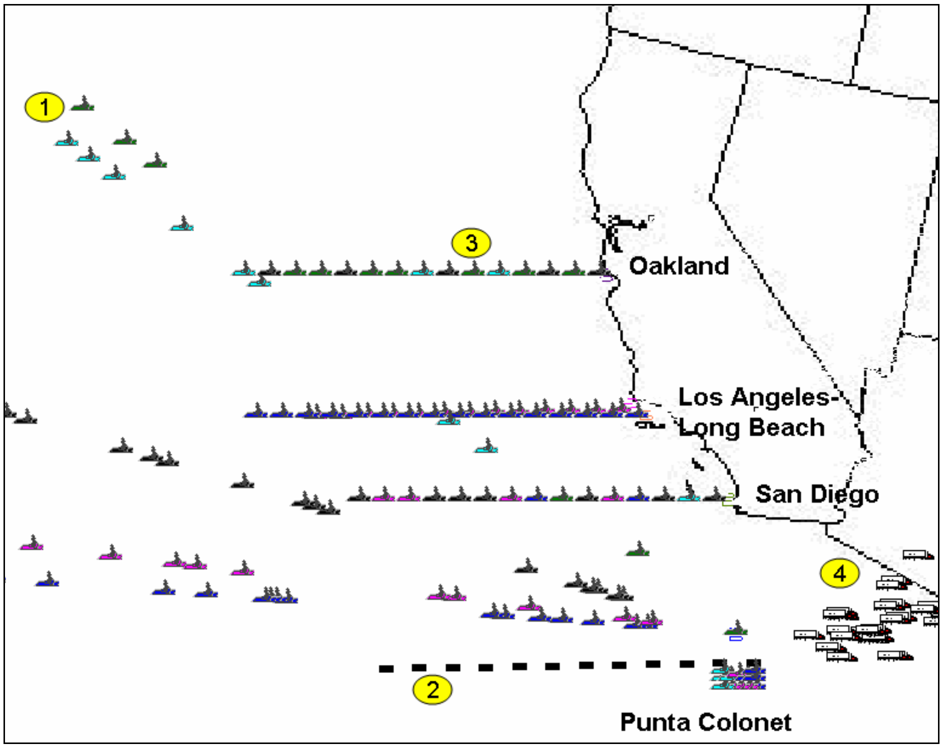

Figure 43. Snapshot of ILWU+ scenario within Arena. West Coast-bound vessels (1) divert to Punta Colonet, significant cargo (2) and ship (3) congestion forms along the coast, and (4) cargo offloaded in Mexico is shipped back to U.S metropolitan areas.

These 175 vessels (on average) and associated containers constitute 3 percent of the annual U.S. West Coast volume. Ocean carriers calling upon Punta Colonet will incur an additional \$2.49 million (\$14,108 per vessel) in incremental operating costs from the extended Baja California transit; however, Punta Colonet serves as a "relief valve" during the 10-day lockout as 8.06 million TEUs transition from U.S. West Coast ports. This container throughput figure is the most significant value encountered in all of our scenarios (see Table 14 and Figure 44).

## Scenario: ILWU Lockout (+)

| Ship Bound For: | Ship Throughput | Ship Operating Costs ($K) | Container Yard Demurrage ($K) | Import Containers (TEUs) | Scheduled Utlization | | | Waiting Time (Hours) | | Queue Length | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Average* | *Average* | *Average* | *Average* | *Average* | *Min* | *Max* | *Average* | *Max* | *Average* | *Max* |
| **Long Beach (Berth)** | 1,635 ± 3 | 5,127 ± 73 | - | 2,639,446 ± 4,171 | 0.26 ± 0.00 | 0.23 | 0.29 | 2.35 ± 0.03 | 239.99 | 0.48 ± 0.01 | 38 |
| **(CY)** | - | - | 144,885 ± 588 | - | 0.13 ± 0.00 | 0.12 | 0.15 | 1.35 ± 0.03 | 240.00 | 0.27 ± 0.01 | 32 |
| **Los Angeles (Berth)** | 983.75 ± 1.98 | 3,155 ± 55 | - | 3,359,683 ± 6,897 | 0.54 ± 0.00 | 0.47 | 0.63 | 2.41 ± 0.04 | 240.00 | 0.30 ± 0.01 | 23 |
| **(CY)** | - | - | 192,472 ± 995 | - | 0.13 ± 0.00 | 0.11 | 0.15 | 2.07 ± 0.04 | 239.98 | 0.25 ± 0.00 | 28 |
| **Oakland (Berth)** | 1,707 ± 3 | 5,398 ± 71 | - | 564,972 ± 867 | 0.11 ± 0.00 | 0.10 | 0.12 | 2.37 ± 0.03 | 240.00 | 0.51 ± 0.01 | 35 |
| **(CY)** | - | - | 4,110 ± 57 | - | 0.06 ± 0.00 | 0.06 | 0.07 | 0.26 ± 0.01 | 240 | 0.06 ± 0.0 | 13 |
| **Portland (Berth)** | 122.72 ± 0.68 | 388.70 ± 19.88 | - | 57,401 ± 326 | 0.09 ± 0.00 | 0.06 | 0.14 | 2.38 ± 0.12 | 243.20 | 0.04 ± 0.00 | 6 |
| **(CY)** | - | - | 156.78 ± 2.58 | - | - | - | - | 0.09 ± 0.03 | 239.91 | - | 3 |
| **Punta Colonet (Berth)** | 175.32 ± 0.84 | 2,469 ± 19 | - | 241,504 ± 1,522 | 0.04 ± 0.00 | 0.02 | 0.05 | 11.54 ± 0.61 | 139.43 | 0.26 ± 0.01 | 76 |
| **(CY)** | - | - | 175.88 ± 1.93 | - | - | - | - | - | - | - | - |
| **San Diego (Berth)** | 44.29 ± 0.42 | 132.94 ± 11.67 | - | 40,070 ± 385 | 0.02 ± 0.00 | 0.01 | 0.04 | 2.26 ± 0.20 | 239.89 | 0.01 ± 0.00 | 4 |
| **(CY)** | - | - | 646.85 ± 18.13 | - | 0.04 ± 0.00 | 0.02 | 0.06 | 0.17 ± 0.06 | 238.56 | - | 2 |
| **Seattle (Berth)** | 681.89 ± 1.65 | 2,165 ± 47 | - | 593,420 ± 1,473 | 0.26 ± 0.00 | 0.22 | 0.31 | 2.38 ± 0.05 | 239.99 | 0.20 ± 0.00 | 19 |
| **(CY)** | - | - | 33,363 ± 213 | - | 0.09 ± 0.00 | 0.08 | 0.10 | 0.70 ± 0.03 | 240.00 | 0.05 ± 0.00 | 9 |
| **Tacoma (Berth)** | 505.48 ± 1.38 | 1,614 ± 41 | - | 571,198 ± 1,603 | 0.31 ± 0.00 | 0.25 | 0.37 | 2.39 ± 0.06 | 266.35 | 0.15 ± 0.00 | 17 |
| **(CY)** | - | - | 10,318 ± 71 | - | 0.07 ± 0.00 | 0.06 | 0.08 | 0.83 ± 0.04 | 239.99 | 0.05 ± 0.00 | 8 |
| **Total West Coast (Berth)** | 5,855 | 20,449 ± 130 | - | 8,067,694 ± 8,507 | - | - | - | - | - | - | - |
| **(CY)** | - | - | 386,130 ± 1,157 | - | - | - | - | - | - | - | - |

Note: CY stands for container yard and a cell marked with a hyphen (-) indicates a negligible value.

Table 14. Data output from CPMS ILWU (+) scenario. The Port of Punta Colonet, Mexico services on average 175 West Coast-bound ships during the lockout. With Punta Colonet accessible to shippers, West Coast container throughput records the highest value encountered in all of our scenarios (8.06 million). However, the extended transit time to Punta Colonet increases the incremental operating costs of shippers by $20.4 million, or $3,492 per ship.

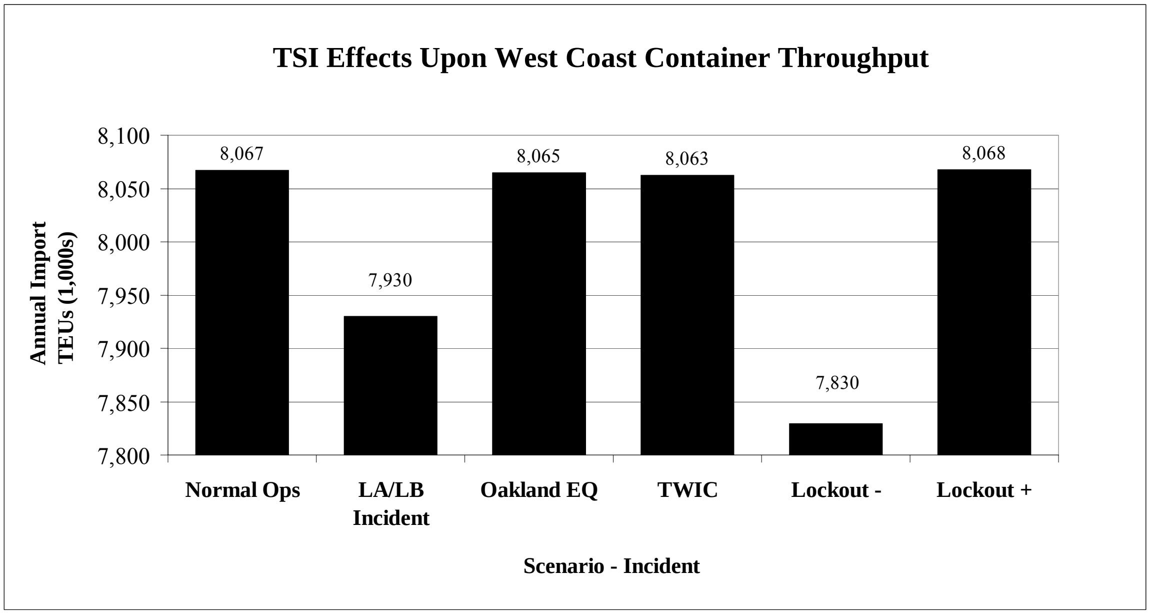


Figure 44. This figure shows the West Coast container throughput for all scenarios modeled. With Punta Colonet accessible to West Coast-bound vessels (ILWU+), the annual container throughput of 8.06 million TEUs is the most significant value encountered in all scenarios.

A labor dispute along the U.S. West Coast inflicts significant congestion to ports and terminals. West Coast volume is degraded by 3 percent and incremental costs to shippers exceed $400 million. However, the proposed Mexican mega-port of Punta Colonet would serve as a viable option for shippers to ensure the unimpeded continuity of operations of the West Coast shipping industry subsequent to a TSI.

## C. SUMMATION

Even under normal operating conditions, ocean carriers are susceptible to sporadic harbor and terminal congestion stemming from the random arrival rates and times to unload and load container ships. Larger ports with higher traffic intensities such as Los Angeles, Long Beach, and Oakland are renowned for such congestion; however, analysis reveals smaller Pacific Northwest ports with less infrastructure are similarly challenged.

An incident simultaneously incapacitating the ports of Los Angeles and Long Beach for an extended period of time places a considerable strain on the remaining

West Coast infrastructure. Our analysis reveals the additional congestion and inability of remaining West Coast seaports to accommodate such volume can be expected to cost ocean carriers upwards of $439 million for operating and cargo storage fees alone. Our modeling does not take into account the secondary and tertiary effects on local, national, and global economies.

Our results show that incapacitating the Port of Oakland or a moderate reduction in West Coast seaport personnel for a two-week period will inflict minimal impact to the West Coast shipping industry. Los Angeles's robust infrastructure and proximity to the Port of Oakland can easily accommodate diverted vessels and cargo, while minimizing the incremental costs to ocean carriers and the impact upon adjacent coastal infrastructure.

A labor union dispute, paralyzing the operations of the West Coast shipping industry, inflicts considerable congestion to seaports, substantial incremental costs to shippers, and presumably also poses significant financial setbacks to local, national, and global economies. However, the availability of the a proposed Mexican mega-port would serve as a viable option for shippers to ensure the unimpeded continuity of operations of the West Coast shipping industry subsequent to a TSI.

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# V. CONCLUSIONS AND FUTURE RESEARCH

This thesis introduces the CPSM, which can be used to estimate the effects of congestion on U.S. West Coast container ports and shipper costs subsequent to a TSI. By constraining the model with abnormal conditions, we are able to identify seaport and intermodal congestive areas that are potential bottlenecks and, thus, are vulnerable to a TSI. Such infrastructure vulnerabilities threaten our maritime shipping capacities and are candidates for incremental commercial investments or government subsidies.

Six representative hypothetical West Coast scenarios have been analyzed. We conclude that West Coast ocean carriers are subject to sporadic congestion and incremental demurrage fees beyond normal routine. This congestion is attributable to the random arrivals, servicing, and varying load dimensions of the modern-day shipping industry. We determine there is insufficient West Coast infrastructure to accommodate an event incapacitating the ports of Los Angeles and Long Beach beyond a two-week period. Such an event would render a strain so significant that annual West Coast volume could be expected to decrease by 2 percent (61 ships and 136,471 TEUs), with incremental expenses to ocean carriers exceeding $439 million. Conversely, the West Coast has sufficient infrastructure in place to accommodate crises incapacitating the Port of Oakland or a coastwide administrative reduction in seaport personnel. Lastly, we find a labor union dispute the most significant threat to the vitality of the West Coast shipping industry. We find a 10-day dispute reduces the annual West Coast volume by 3% (175 ships and 237,088 TEUs) and inflicts additional expenses exceeding $400 million on shippers.

Follow-on work can include improving the model's scalability (i.e., reducing the number of Arena modules required), while enhancing model logic to include additional intermodal and transportation modes as influenced and directed by experts of intermodal planning and transportation systems.

Additions to the model might also include the development and analysis of additional ocean-carrier concepts to include strategic and domestic commodities and cargoes (e.g., bulk, break-bulk, and petroleum).

Finally, synchronizing the model with an optimization package such as OptQuest (Arena, 2008) within Arena can assist CPSM in determining optimal routing decisions for diverted vessels and approximate locations for additional seaport infrastructure investments. This can be done by defining various inputs and constraints (e.g., cost, distance, or capacity) and desired outputs in the form of an objective function and expressing binary options to enhance infrastructure. OptQuest then performs heuristic local search, using the simulation model to evaluate candidate designs, hoping to discover improvements.

# APPENDIX A. CPSM ENTITY CREATION STAGE


Figure 45. The first stage of CPSM creates ship entities for each seaport of our research and assigns each a port-of-call and animation properties. This stage is presented in detail in Chapter III.

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APPENDIX B. CPSM PORT ROUTING LOGIC STAGE

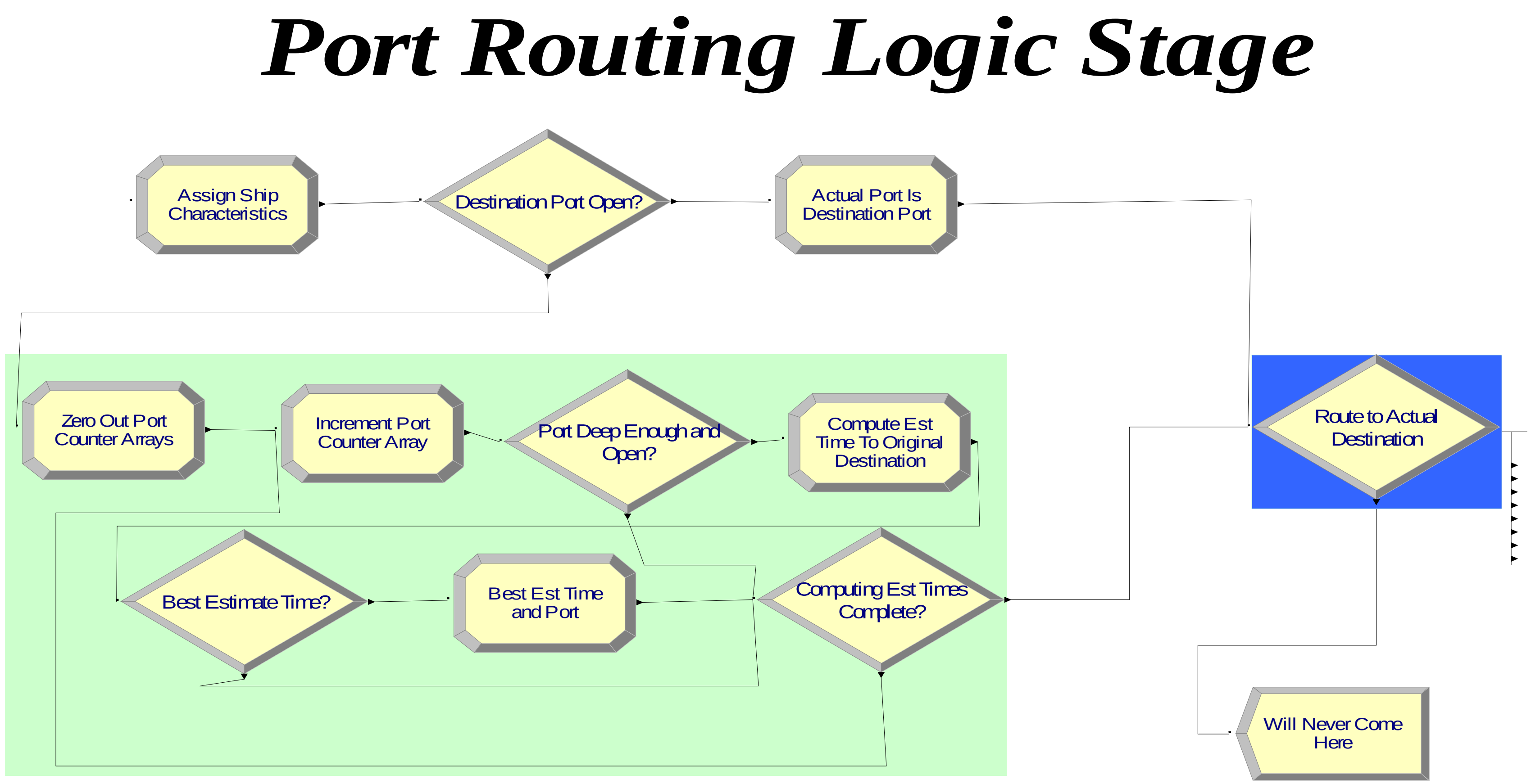


Figure 46. The second stage of CPSM simulates our seaport routing logic in case a ship needs to choose an alternate destination subsequent to a TSI. This stage is presented in three substages within Chapter III.

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# APPENDIX C. CPSM TERMINAL PROCESSING STAGE

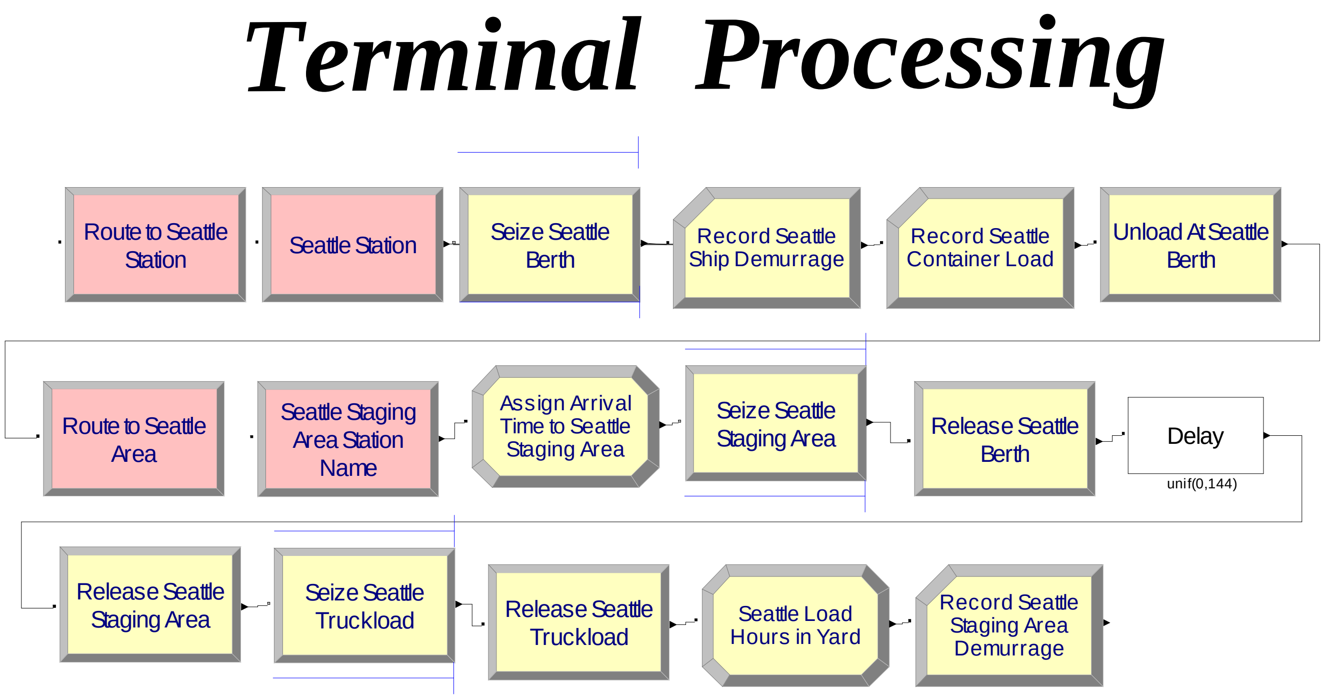


Figure 47. The third stage of CPSM simulates the ship berthing and container yard operations of the shipping industry. This stage is presented in three substages within Chapter III. This stage is voluminous. For exposition, modules representing only the Port of Seattle are presented.

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## APPENDIX D. CPSM LANDSIDE ROUTING LOGIC STAGE

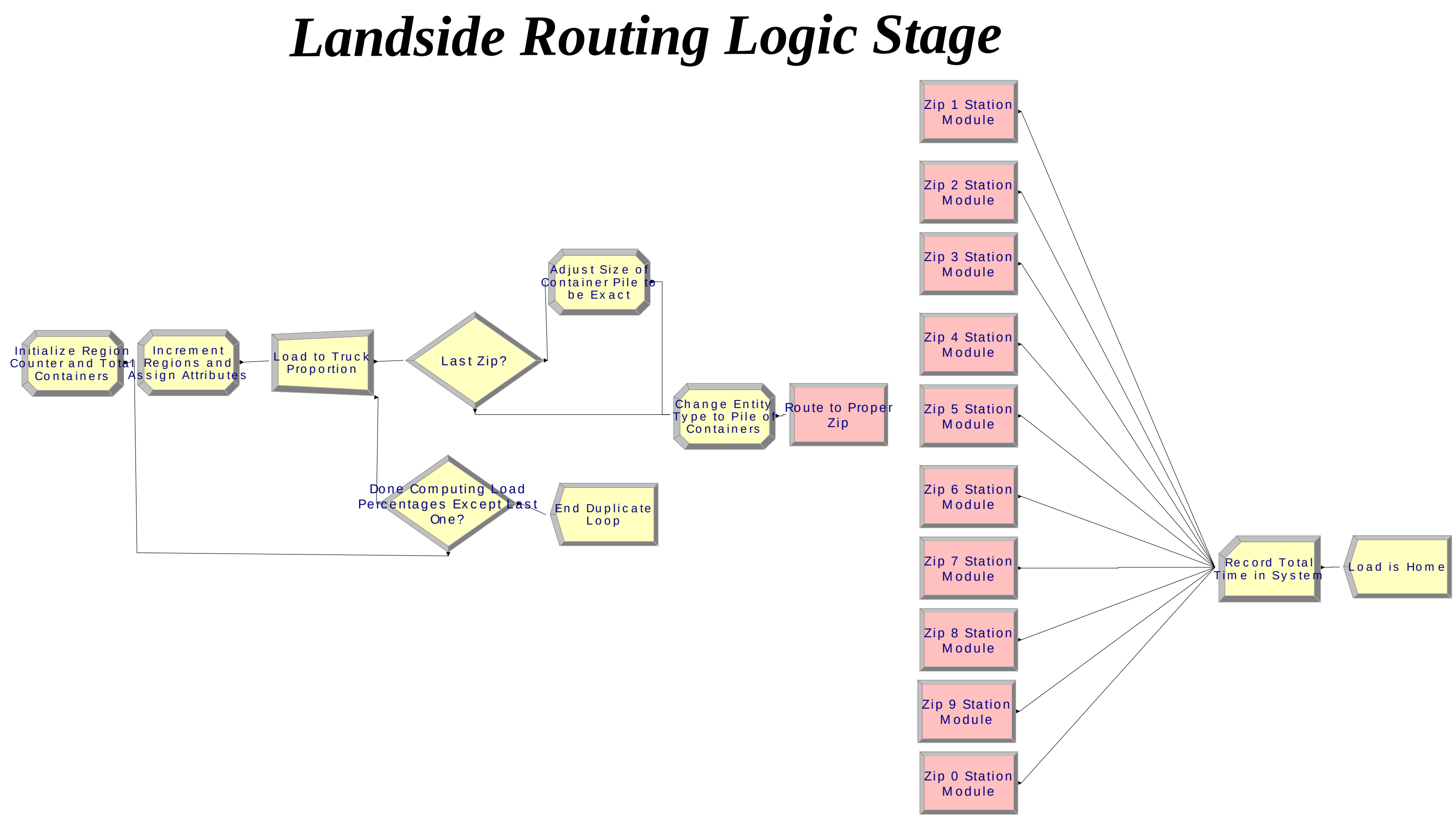


Figure 48. The fourth stage of CPSM simulates cargo routing from seaport terminals to metropolitan areas throughout the United States. This stage is presented in three substages within Chapter III.

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# APPENDIX E. CPSM ANIMATION

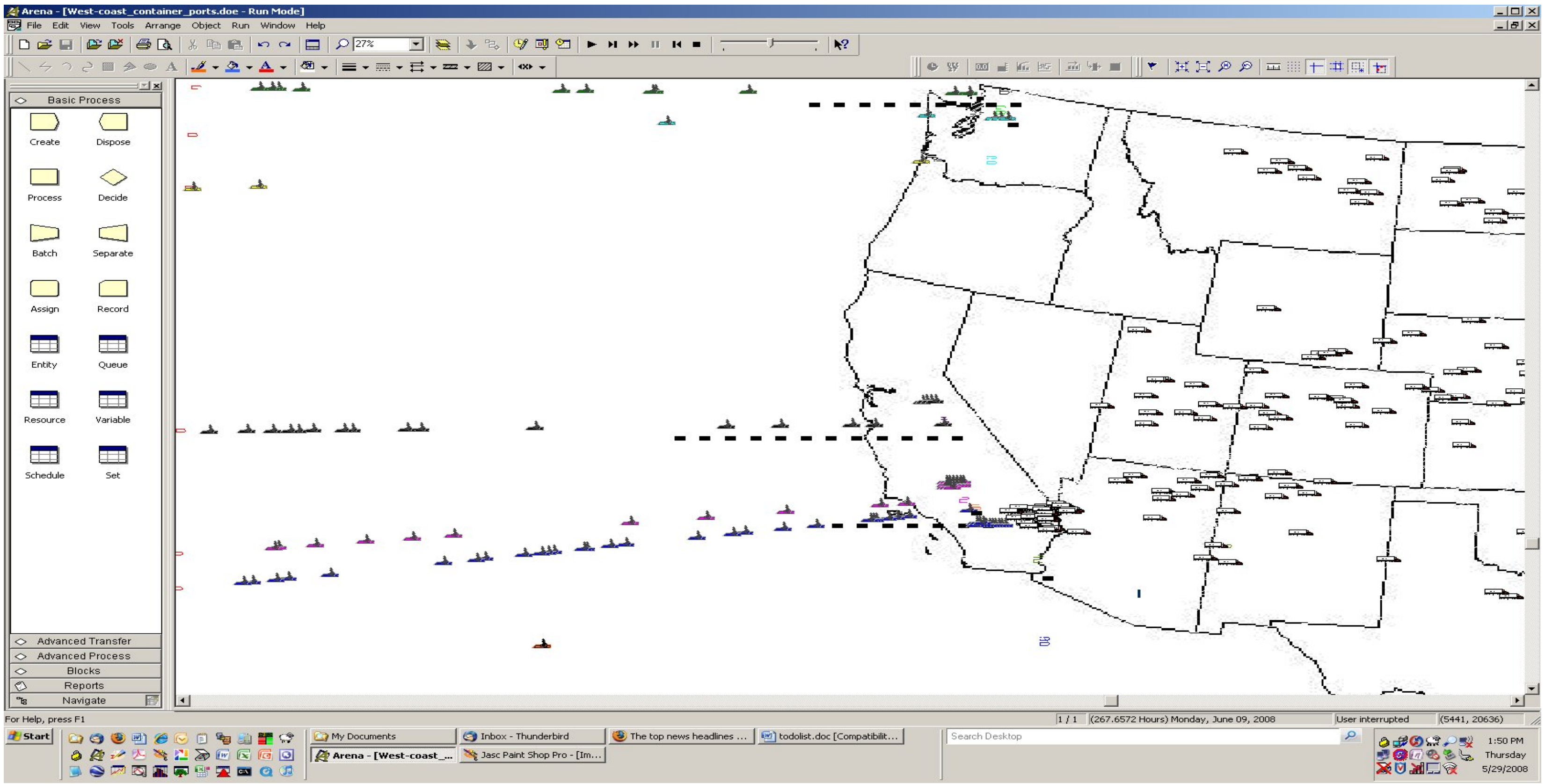


Figure 49. Container Port Simulation Model (CPSM) animation within Arena. The animation shows ship icons arriving to West Coast seaports and the subsequent accumulation of container cargo (black boxes). Containers are ultimately trucked to destinations throughout the United States.

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# LIST OF REFERENCE


AAPA (American Association of Port Authorities). (2008). North American Port Container Traffic. Retrieved in April 2008 from http://aapa.files.cms-plus.com/PDFs/North_American_Container_Traffic.pdf.

Aitoro, J. (2008). Less than Eight Percent of Port Workers Have New Security Cards. *Government Executive*. Retrieved in May 2008 from http://www.govexec.com/story_page.cfm?articleid=39977&dcn=e_hsw.

Arena. (2008). OptQuest. [computer software]. Retrieved in May 2008 from http://www.arenasimulation.com/products/optquest.asp.

Baja Insider. (2008). Major Seaport Proposed for Baja California Norte. Retrieved in May 2008 from http://www.bajainsider.com/environment/port-punta-colonet.htm.

BOC (United States Department of Commerce, Bureau of the Census). (2006). Value of Merchandise Trade. Retrieved in March 2008 from http://trade.gov/index.asp.

BTS (Department of Transportation, Bureau of Transportation Statistics). (2007). America's Container Ports: Delivering the Goods. Retrieved in January 2008 from http://www.bts.gov/publications/americas_container_ports/pdf/entire.pdf.

D'Silva, A. (2008). Personal communication to the author. Email 10 March 2008.

Demographia. (2008). Consolidated/Metropolitan Statistical Areas (County Based). Retrieved in March 2008 from www.demographia.com/db-metmic2004.pdf.

Devore, J. (2004) *Probability and Statistics for Engineering and the Sciences*. Duxbury Press. Sixth Edition.

DOT (Department of Transportation). (1999). An Assessment of the U.S. Marine Transportation System. A Report to Congress. ReC63A80-397A-46D0-BB85-4E3trieved in May 2008 from http://www.marad.dot.gov/Publications/MTSreport/chapters/themts.pdf.

Falche, A. (2007). Personal communication to author. Email 10 April 2008.

GAO (United States Government Accounting Office). (2005). Port and Maritime Security: Background and Issues for Congress. May 27, 2005. Retrieved in January 2008 from http://www.gao.gov/htext/d05448t.html.

Google Earth. (2008). Various maps of U.S. locations. Retrieved in January 2008 from http://www.earth.google.com.

Hanson, W. (2008). Personal communication to the author. Email 24 April 2008.

Internationalist. (2002). PMA Bosses' Lockout: A Declaration of War on Longshore Workers and All Labor. Retrieved in May 2008 from http://www.internationalist.org/ilwulockout1002.html.

JANES. (1994). *Janes Containerisation Directory, 1993-1994*. Twenty-Fifth Edition. 449-453.

Kelton, W., Sadowski, R., & Sturrock, D. (2007). *Simulation With Arena*. Fourth Edition. Warrendale, PA: McGraw-Hill.

Lloyd's Register. (2008). Boxship 2007. Large Containerships and the NPX. Retrieved in May 2008 from http://www.lr.org/NR/rdonlyres/19C63A80-397A-46D0-BB85-4E38557EC69A/71593/Boxship2007LargeContainerShips andtheNPX1.pdf.

MARAD (Department of Transportation Maritime Administration). (2005). Report to Congress on the Performance of Ports and the Intermodal System. June 2005. Retrieved in January 2008 from http://www.marad.dot.gov/Publications/ 05percent20reports/Reportpercent20topercent20Congress-Portspercent20percent20Intermodalpercent20Efficiencypercent 206-21-05percent20final.pdf.

MARAD (Department of Transportation Maritime Administration). (2008a). U.S. Port Calls By Ports and Vessel Type, 2002-2006. Retrieved in February 2008 from http://www.marad.dot.gov/MARAD_statistics/2007percent20STATISTICS/ vcalls2002-2006.xls.

MARAD (Department of Transportation Maritime Administration). (2008b). U.S. Waterborne Foreign Container Trade by U.S. Custom Ports, 1997-2006. Retrieved in March 2008 from http://www.marad.dot.gov/MARAD_statistics/ 2005percent20STATISTICS/Containerpercent20Custompercent20Ports,percent20 1997-2006.xls.

Martin Associates. (2007). *The Economic Impacts of Containerized Cargo Moving Via the West Coast Ports*. Lancaster, PA: Martin Associates.

Mashagbeh, W. (2008). Personal communication to the author. Email 15 April 2008.

MTSA (Maritime Transportation Security Act). (2002). Maritime Transportation Security Act of 2002. Retrieved in April 2008 from http://www.tsa.gov/assets/ pdf/MTSA.pdf.

NSMS (National Strategy for Maritime Security). (2005). The National Strategy for Maritime Security. Retrieved in March 2008 from http://www.whitehouse.gov/homeland/maritime-security.html.

NVMC (National Vessel Movement Center). (2007). Notice of Arrival. Retrieved in December 2007 from https://www.nvmc.uscg.gov/Forms/33cfr160 Feb28_Final.pdf.

PMA (Pacific Maritime Association). (2006). 2006 Annual Report. Retrieved in January 2008 from http://www.pmanet.org/pubs/AnnualReports/2006/PMApercent202006percent20Annualpercent20Report,percent20pagespercent2056-81.pdf.

POLA (Port of Los Angeles). (2008). The Port of Los Angeles. Retrieved in February 2008 from http://www.portoflosangeles.org.

POLB (Port of Long Beach). (2008). The Port of Long Beach. Retrieved in February 2008 from http://polb.com.com.

POO (Port of Oakland). (2008). The Port of Oakland. Retrieved in February 2008 from http://www.portofoakland.com.

POP (Port of Portland). (2008). The Port of Portland. Retrieved in February 2008 from http://www.portofportland.com.

POSD (Port of San Diego). (2008). The Port of San Diego. Retrieved in February 2008 from http://www.portofsandiego.org.

POS (Port of Seattle). (2008). The Port of Seattle. Retrieved in February 2008 from http://www.portseattle.org.

POT (Port of Tacoma). (2008). The Port of Tacoma. Retrieved in February 2008 from http://www.portoftacoma.com.

Ross, S. (1998). *A First Course in Probability*. Fifth Edition. Upper Saddle River, NJ: Prentice Hall.

Takus, D., & Profozich, D. (1997). Arena Software Tutorial. Winter Simulation Conference. Retrieved in January 2008 from http://delivery.acm.org/10.1145/270000/268564/p541-takus.pdf.

TSA (Transportation Security Administration). (2008). Transportation Worker Identification Credential (TWIC). Retrieved in May 2008 from http://www.tsa.gov/what_we_do/layers/twic/twic_faqs.shtm.

USCB (United States Census Bureau). (2008). Basic Counts-Population. Retrieved in May 2008 from http://www.factfinder.census.gov/servlet/ACCSAFFPeople?_see=on&_submenuId=people_1&_ci_nbr=&qr_name=&ds_name=&reg=&_industry=.

USCG (United States Coast Guard). (2008). Marine Transportation System. Retrieved in May 2008 from http://www.uscg.mil/hq/g-cp/comrel/factfile/Factcards/MTS.htm.

White, R. (2008). Dockworkers, Ship Owners to Begin Talks. *The Los Angeles Times*. Retrieved in March 2008 from http://www.montereyherald.com/ci_8600704.

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